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The Common Storage

Its Construction and Management

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CONTENTS

THE COMMON STORAGE
Its Construction and Management

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INTRODUCTION

All fruit growers and particularly those interested in the storage and marketing of apples agree that there is no substitute for cold storage for several of the commercial varieties. However, in the absence of cold storage facilities, a good air-cooled storage is much superior to a barn or pit storage since the insulated walls and ceiling and ventilation systems permit the maintenance of lower average temperatures in the fall and ample protection from freezing in the winter. In addition, there is some economy in constructing a good common storage, which at some later date may very easily be converted into a cold storage through the installation of artificial refrigeration.

The principles of construction and management of air-cooled storages, as well as materials for insulation, are discussed in this bulletin on the basis of results with an experimental storage and with commercial storages over the State.

In air-cooled or common storages, where no artificial method of refrigeration is used, the temperature of the fruit is usually close to the average temperature prevailing outside. During the months of October and November there are many periods when the temperature is high. As a result, the fruit ripens prematurely; also, excessive heat invariably impairs the quality of the fruit. From the early part of December until the end of the storage season weather conditions are usually such that the temperature of the fruit is nearly that found in cold storages, but even the most favorable conditions during this period cannot compensate for the damage done by improper storage during the early part of the season.

Alexander (1) has published weather maps showing the normal temperature distribution during all months of the year for Ohio. Although mean temperatures for daily, weekly, and monthly periods vary with locality and season, observations for 40 to 50 years reveal a 10-degree reduction in temperature per month from 63-69° (north to south) in September, 52-57° in October, 40-45° in November, to 28-35° in December. These mean monthly temperatures will vary by not more than 5 degrees (usually about 3 degrees) during a period as long as 40 years. The daily range in temperature will be from 15 to 20 degrees and the daily variability from 3 to 6 degrees. It is only in well insulated storages, judiciously managed, that the temperature is as low as that of the outdoor daily mean temperature, and usually it is somewhat above the mean for a 10-day period or longer. From records taken in several localities and for several seasons, it was found that, although the average storage temperature during a period as long as 10 days was sometimes above and at other times below the outdoor mean temperature during the same interval (6 to 10 degrees F. fluctuations), the mean values showed a storage temperature about equal to that prevailing outside during October and slightly above during November and December (1 and 3 degrees F., respectively).

[1]Acknowledgments.—The author wishes to acknowledge the kindness of Dr J. H. Gourley, Dr. F. S. Howlett, and C. W. Ellenwood in reading the manuscript and offering helpful suggestions. Appreciation is due the many storage operators who cooperated in securing data.

For a good many years the design of common storages has been based upon physical principles; i. e., since a given volume of warm air is lighter than an equal volume of cold air, air movement results from the pressure difference. Air in contact with fruit becomes warmed and then is displaced by cooler, heavier air which forces the warmed air up out of the storage.

The usefulness of various materials for construction purposes is well understood by architects, contractors, and building supply dealers, if not by the fruit grower. What is not commonly appreciated is the severity of the conditions imposed upon materials used in common storages. Buildings constructed of poor materials improperly installed may be in need of repair or rebuilding in a surprisingly short time.

There is probably no other material used in storage construction about which the grower knows so little as insulation. Over 80 materials are now being sold as insulation and many more are being introduced every year, so that even the better informed builders find it difficult to choose the best insulation for a specific requirement. However, the number of materials possessing merit for use under the severe conditions found in storages is not large.

FACTORS AFFECTING THE QUALITY OF STORED FRUIT

THE RIPENING PROCESSES

The storage of apples is complicated by the fact that a fruit, even after its removal from the tree, continues certain life processes throughout its storage period. By picking time nearly all the starch is changed to sugar. In storage, the sugar is oxidized to carbon dioxide and water, which are given off, together with considerable heat. As these processes go on the fruit becomes softer, and eventually it will decay if not marketed.

Magness (17) and others have reported a slight increase in the total quantity of sugar in the apple between the time of picking and the time when the fruit is soft. No consistent variation was found in the quantity of total or reducing sugar when the fruit was held at various temperatures. Acidity decreased between the time of picking and that of full ripeness in all varieties and at all temperatures.

IMPORTANCE OF KEEPING FRUIT COOL

These ripening processes take place much more slowly at low than at ordinary temperatures. In practice, it is found that the lower the temperature one can maintain without permanently injuring the tissue, the longer the fruit can be stored in perfect condition. In the case of certain varieties, such as Grimes Golden, Wealthy, and Rome Beauty, the products of respiration may accumulate in sufficient quantities when held at too low temperatures to injure the quality of the fruit permanently; such varieties are sometimes better held at 35° F. or above for a portion of their storage life. For most varieties the most practical storage temperature is close to the freezing point of water.

Magness (17) found the softening rates of different varieties of apples to vary widely when held at 32° F. and to be in about the same order at 40° F., but all varieties softened with great rapidity at 70° F. He points out that most varieties, when held at high temperatures, have a short period after picking when little softening occurs. Following this initial period, softening takes place rapidly; in fact, it may double for each 10-degree rise in temperature above 32° F.

Marshall (19) interprets the exact rate of softening in terms of storage life and concludes that "if a certain variety will reach prime eating condition at 70° in one month from time of picking, the storage season at 50° would be approximately two months; at 40° it would be about four months; and at 32° approximately eight months".

Not only does the low temperature retard the physiological processes in the fruit, but it also slows down the growth of various fungi which rot the apple. It lessens the physiological disorder known as "internal breakdown" but may increase a second disorder known as "internal browning".

In an air-cooled storage it is impossible to maintain a temperature near the freezing point during warm weather. About the best that can be hoped for is to secure a temperature approximately equal to that prevailing during the night. Unfortunately, there frequently are nights with little wind and high temperatures when little cooling is possible.

The temperature for the month of September may vary from an average of 63° in the northern part of the State to 69° in the southern section. The temperature will then drop approximately 10 to 12 degrees per month until in December average temperatures of 28 to 35° will prevail. The longer the apples are left on the tree the longer their storage life, since they will soften more rapidly off the tree at the higher temperatures prevailing in September and October.

After the last of November or the first of December it is theoretically possible to maintain storage temperatures very close to 32-35° F. The reasons why this is not accomplished in practice in all cases are:

Insufficient insulation, allowing the storage temperature to rise during intervals of high temperatures outside.

Heat, evolved by the stored fruit which accumulates in the storage during periods when the outside temperature is high.

Poor storage management.

Inadequate ventilation facilities for removing the heat in the fruit and storage during the limited period (6-12 hours per day) when ventilation may be practiced.

Daily maximum and minimum temperatures prevailing inside and outside of many storages in different parts of Ohio have been obtained through the cooperation of fruit growers. Large variations were found between one storage and another, as well as between seasons. Five storages and two seasons were selected to represent the range of conditions encountered.

The graphs (Fig. 1) show the fluctuation in storage temperature relative to a 32° F. temperature (top line), as well as the efficiency of the storage and management (blackened areas). The blackened areas indicate when the temperature of the outdoor air was below that of the storage air and how far below in degrees Fahrenheit. They may be thought of as representing artificial refrigerating capacity furnished by the cold outside air, the cooling effect being dependent upon the duration of the cold period (width of the blackened area) and its severity (degrees Fahrenheit below the temperature of the storage air or the thickness of the blackened areas).

One characteristic common to all storages is the more or less rapid decline in the storage temperature (top line on graphs) near the close of November. This is undoubtedly due in part to the loss of the field heat and the heat which the fruit respires during the early storage period. Moreover, near the last of November nights of relatively low temperatures become more frequent, and within a few days the temperature of the fruit may be dropped several degrees. This more rapid drop in fruit temperature is also due to the fact that the storage is usually full by this time and the room may be kept closed.

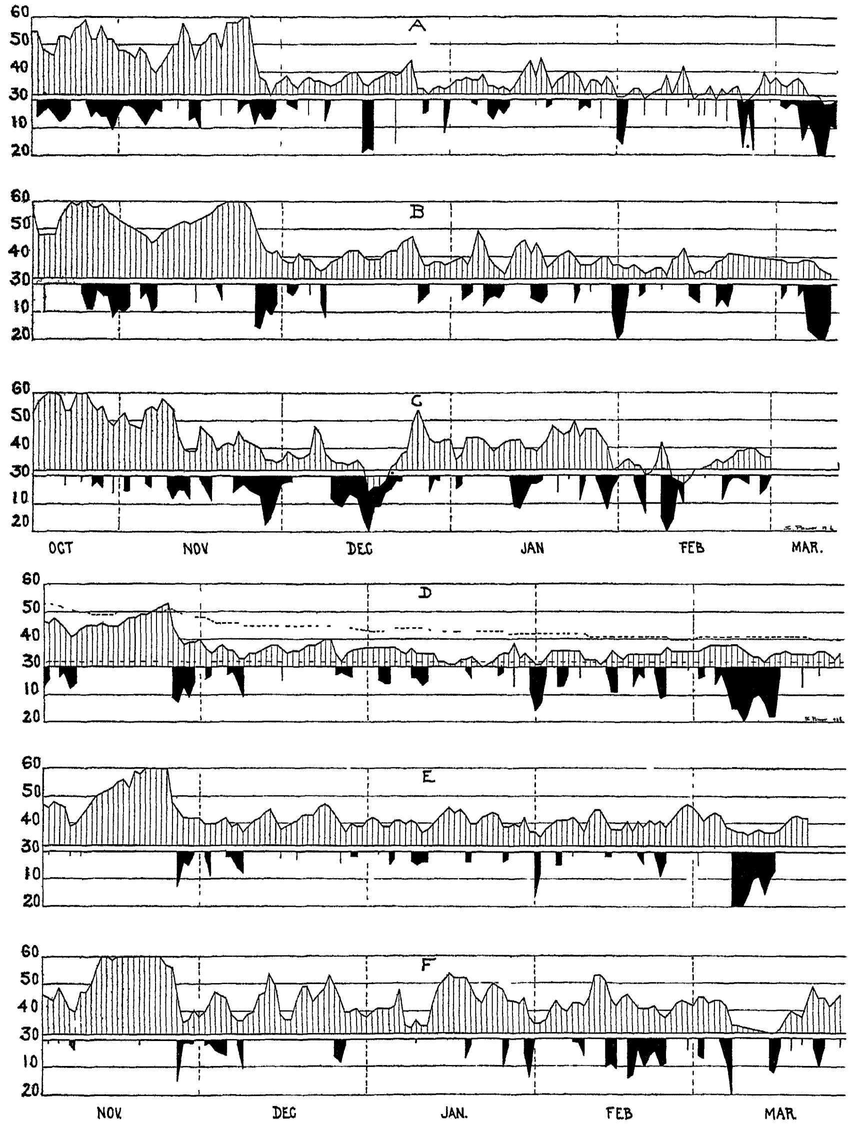


Fig. 1.—Graphs of daily mean storage temperatures and inside to outside air temperature differentials

Graphs A, B, D, E, and F are for 1931-1932 and Graph C is for 1932-1933

The upper half of each graph shows the relation of the daily mean storage air temperature (top line) to a cold storage temperature of 32° F. (horizontal line). The lower half shows the efficiency of the storage and management by means of the blackened areas which indicate when the temperature of the outdoor air was below that of the storage air and the extent of this difference (degrees Fahrenheit).

One of the better constructed and managed storages in Ohio is located along Lake Erie and employs the "Magness" system of ventilation. The temperature prevailing in the storage during the 1931-1932 season is represented in the upper graph, Figure 1A. The temperature (top line) was maintained between 32° and 35° F. after the first of December; this represents a very satisfactory temperature for apples. Note how rapidly the storage temperature rose during those periods when the outside temperature was high and no cooling could be accomplished. It is during these periods that the maximum of insulation and a good forced-draft ventilation are of particular value to take full advantage of extremely short periods of cool, early morning air.

Figure 1B shows the temperatures prevailing in a storage of good construction but poorly managed. It may be compared with the storage on Lake Erie, which is only 50 miles farther north. In spite of poor management the temperature maintained was fairly satisfactory. Due to the fact that the fluctuations in storage temperature were not over 6 to 10 degrees, it seems doubtful if such changes were injurious, since there is no evidence that fruit keeps better with a constant temperature than with slightly fluctuating temperatures, the average of which is that of the constant temperature.

Graphs C and F were obtained from temperatures recorded in the same storage during two seasons. Note the favorable early fall weather (November 1932, Figure 1C) which permitted the operator to lower the temperature rather rapidly during the crucial storage period. This should be contrasted with the exceedingly high storage temperature prevailing during the same month in the same storage in 1931, Figure 1F. With the proper insulation in this storage the rise in storage temperature during the remainder of the season both years could have been avoided.

Figure 1E shows the temperatures maintained in a large (25,000-bushel), well insulated storage in Fairfield County. This is an excellent example of the results which may be expected in a large storage which is well managed. Note the fairly even temperature which it was possible to secure with plenty of insulation to prevent the entrance of heat between periods of low outside temperatures. The blackened areas on the graph are small and infrequent, indicating that full use was made of all periods of low outside air temperatures. In spite of this fact, the storage temperature was higher than was desirable, possibly because of inadequate ventilation. The owner of this storage has since installed fans for forced ventilation, with considerable improvement during seasons of relatively high outside temperatures.

In a small (2800-bushel) underground storage constructed at the Ohio Experiment Station for experimental purposes, soil and storage air temperatures were recorded and are presented in Figure 1D. Note the uniform soil temperature (dotted line) which would be approximately the same as the air temperature in closed underground storages. Plenty of ventilation is essential to lower the fruit temperature below that of the soil in such storages and explains why above-ground storages are preferred for apples. The continuous line in this graph represents the air temperature and indicates what may be accomplished in such storages with ample ventilation.

A good many well distributed openings and exhaust fans enabled the operator to maintain a very satisfactory fruit temperature in this experimental storage in spite of the constant heating effect of the earth floor and earth-banked walls and ceiling.

In general, the data presented in Figure 1 are encouraging, considering the very warm autumn of 1931. From a study of the temperature data secured in all parts of Ohio over a period of several years these conclusions may be drawn:

1. The storage temperature during the fall months tends to follow the mean outdoor temperature or to be slightly above, due to the heat entering the storage with the fruit (field heat) and through frequent opening of the storage doors.

2. The daily temperature fluctuation within the storage is negligible.

3. Rapid upward change in storage temperature may be eliminated by proper air sealing, good insulation, and proper early fall management. Any rise in the temperature of the walls, crates, and fruit during short periods of high outdoor temperatures increases the difficulty in maintaining a satisfactory mean storage temperature over an extended period of time.

4. A mean storage temperature approximately equal to the average mean outdoor temperature over a period as long as 10 days may be expected under good air-cooled storage management in most of Ohio.

5. Cold storage temperatures of 32 to 35° F. are attainable in air-cooled storages by the first of December during favorable seasons. Good construction and management are necessary to the maintenance of such temperatures during December.

Methods of removing field heat.—Since the greatest damage to fruit in common storages occurs during the period before the first of December, the question arises as to whether there might not be some means of removing field heat and lowering fruit temperatures to 40° F. or below during the early storage period. Baker and Mayer (8) have reported on the value of ice in reducing fall temperatures in an air-cooled apple storage in southern Indiana. By means of air circulation over blocks of ice they were able to reduce storage temperatures from 10 to 16 degrees F. below the temperature of a similar room cooled by ventilation and from 18 to 22 degrees F. when using cracked ice and salt, during September and October. However, the actual storage temperature was never below 40° F. and averaged 45° F.

Grimes and Jonathan stored in the iced room remained in good market condition for several weeks longer (until late November and early December) than when kept in the ventilated room. This difference in the condition of the fruit from the two rooms gradually disappeared after the middle of December, and by the middle of January there usually was little difference in the quality of the two lots of fruit. The ventilated apples shriveled readily while the relative humidity in the iced room remained satisfactory for apple storage. The seasonal cost of icing and operating the iced room in this experiment varied from 16 to 26.6 cents per bushel, with an average of 20.8 cents per bushel for the 6 years. The economy of ice in cooling storage rooms is somewhat doubtful and would depend upon the price of ice and the rise in market prices of fruit as the season progressed.

At the present time many growers are investigating the advisability of installing artificial refrigeration in their storages. An encouraging development is now taking place in the field of refrigeration through the use of air-conditioning equipment in produce storages. Where freezing temperatures are to be maintained, "brine spray" or "wet coil" types of unit coolers are employed which both circulate the air and control its humidity, in addition to removing the heat from the fruit. By means of power fans, semi-flooded-coil or fin-type coolers, and a refrigeration temperature of approximately 35° F., a small amount of equipment operating on one-half to one-third the normal horsepower is capable of keeping apples in prime condition, with no shriveling, well through the normal marketing season. A few such installations have been made for approximately 18 cents per bushel capacity. Such a system of refrigeration is based on a relatively high refrigerant temperature with sufficient overload capacity to lower the temperature of a storage room full of fruit at a moderate speed. This requires no oversized equipment which, after the tremendous "pull-down" cooling load has been removed, lies idle a great proportion of the time.

EFFECT OF THE RELATIVE HUMIDITY ON APPLE FRUITS

The wilting or shriveling of apples is probably the most serious problem confronting the owner of an air-cooled storage. Few growers realize how extremely difficult it is to maintain high humidities in storage rooms when open in the fall or even during the later storage period without an ample water supply close at hand.

There is a wide variation in the tendency of different varieties of apples to wilt; however, it is well to maintain a uniformly high relative humidity regardless of the variety being stored. There is no indication that high humidities are deleterious in any way to the fruit, and, if it were not for the fact that destructive molds grow well above 90 per cent relative humidity, this figure would not be too high. A relative humidity of 85 per cent will prevent wilting of the thin-skinned varieties when stored in open containers or when under ripe, so that it is well to endeavor to maintain the air at from 85 to 88 per cent of saturation.

At times, especially during periods of low temperature and no ventilation, such high humidities result in sweating. Enough insulation could be placed in the walls and ceiling to raise the temperature of the wall surface above the dew point, but the extra cost is not justifiable from an economic standpoint. A slight movement of air such as would be afforded by opening the ventilation system will reduce sweating. It is preferable, however, to permit some growth of molds[2] on floors, walls, and containers rather than to permit wilting of the fruit.

An occasional examination of thin-skinned varieties and the use of inexpensive wet and dry bulb thermometers will aid in deciding when water should be applied. Wetting the floor and even the fruit and containers will do no harm when the relative humidity is below 85 per cent.

Records taken in several storages throughout Ohio show some variation in the relative humidity from day to day. During October the relative humidity reached 94 per cent in one storage and the lowest humidity in any storage was 62 per cent, with an average for the month in seven storages of 78 per cent. During November, December, January, and February, the relative humidity was somewhat more uniform in the same storages with monthly averages of 81, 86, 86, and 84 per cent, respectively.

PRINCIPLES OF COMMON STORAGE

Gravity ventilation is the process taking place as a result of the current of air started by the warming effect of the fruit.

Wind pressure (originating from temperature differences in the open) also causes air to move through a storage by creating a pressure on the windward and a suction on the leeward side of the building. The movement of air

[2]Methods of disinfecting storages are given in Ohio Agr Exp. Sta. Spec. Cir. 48, p. 30.

through the storage by the force of the wind alone is dependent upon the direction and velocity of the wind, as well as the shape, size, and position of the building and openings in the storage. "Forced ventilation" is the name applied to air movement caused by winds or artificial means such as fans.

The pressure, due to temperature difference, producing a flow of air through the storage is directly proportional to both the difference in temperature and the vertical distance between inlet and outlet openings.

The above facts aid one in understanding the design of the type of air-cooled storage shown in Figure 2D. The openings in this storage are placed as near the ground level as possible and the outlets as near the highest point on the building as possible. Air will continue to move through the storage as long as the fruit remains warmer than the surrounding air.

The number and size of the openings in the storage are fixed at the time of building and it is important to have them of generous proportions. The grower should exercise judgment in stacking the fruit and thus somewhat facilitate air movement.

TYPES OF COMMON STORAGE

Any building, when properly insulated and provided with sufficient ventilation through openings, may serve very well as an air-cooled storage for apples. Abandoned churches and school houses have frequently been pressed into service as common storages. Many buildings on farms have been converted to storage purposes at a minimum of cost and with considerable success. Special reinforcement may be necessary in the load-bearing floors.

Fruit storages may be constructed entirely below ground with more or less of their wall and roof surfaces exposed or entirely above ground. For convenience, four types are distinguished in this bulletin. There is some overlapping between them.

1. Above-ground. Major portion of the building above ground.
2. Below-ground. Roof and walls completely covered with earth.
3. Basement. The portion of a building below ground.
4. Bank or hillside. Some part of roof or walls or parts of both exposed.

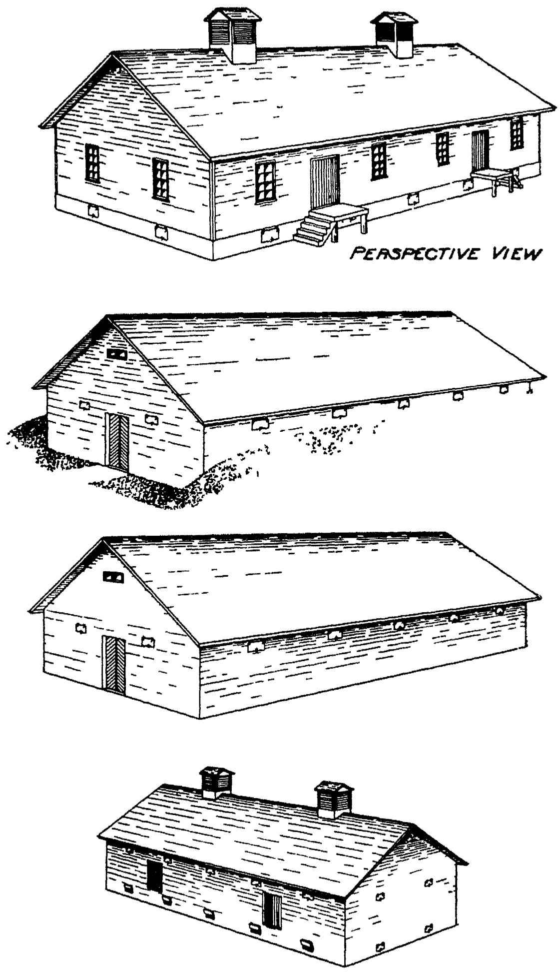
SYSTEMS OF VENTILATION

There are several systems of ventilation and combinations of these employed in the construction of common storages. These systems may be classified as follows:

1. Natural gravity ventilation
   - (a) "Cope" System
   - (b) "Magness" System
   - (c) Combination of (a) and (b)
2. Forced ventilation
   - (a) Power fans
   - (b) Cowl induced
   - (c) Wind pressure

THE "COPE" SYSTEM

Nathan Cope of New Waterford, Columbiana County, Ohio, procured in 1869 a United States patent for his invention, "Improvement in Fruit-Houses". His system utilized the principle of providing for the entrance of cold outside air into a storage house through openings distributed around its walls at the floor level; this air by virtue of its greater weight replaced warmer air which was thus forced out through a flue in the ceiling. This system, with slight modification, is being employed in storage construction quite generally today.



A
Basement

B
Bank

C
Above-ground "Magness" system

D
Above-ground "Combination" system

Fig. 2.—Four types of common or air-cooled storage houses

Combining a grading and packing room with an underground or basement storage (top) is economical of material and space. Note the absence of outlet ventflues in the earth-banked (second from top) and above-ground (third from top) which is characteristic of the "Magness" type. The storage banked with earth would prove the least satisfactory of the four types. A combination of the "Cope" and "Magness" systems of ventilation (bottom) is to be recommended where the greatest satisfaction, irrespective of cost, is desired. (From U. S. D. A. Mimeograph, Washington, D. C.)

THE "MAGNESS" SYSTEM

Many of the older storages in America were built as basements to apple packing houses. The floor of the packing house was usually constructed not more than 2 or 3 feet above the ground level; this provided sufficient space for ventilation openings around the ground line or just below the ceiling of the basement room, Figure 2A. Magness[3], by controlled experiments, established the essential principles in cooling fruit in an air-cooled room. He found that, when the cold air was delivered at the floor of the storage ("Cope" System), the fruit in the lower layers cooled out far more rapidly than the fruit in the top of the stacks. A temperature difference between the top and bottom layers always existed even when the temperature of the bottom layers was at a safe minimum. With air entering only at the room ceiling, the fruit cooled at the same rate throughout the storage and the top layers cooled more thoroughly than when the "Cope" System was employed. He concluded that air inlets on the same level with or above the top of the fruit stacks are absolutely essential to the equal cooling of the fruit, Figure 2C.

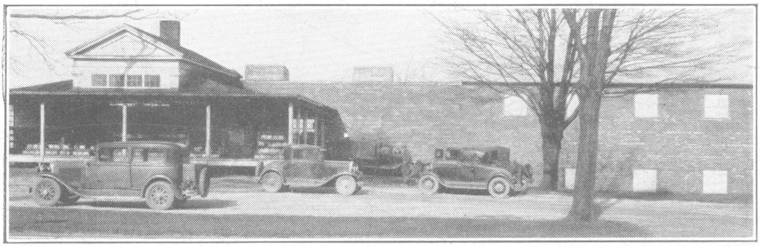


Fig. 3.—Cooperative fruit growers packing and storage warehouse

A very successful and well managed cooperative air-cooled storage, employing the "Magness" System of ventilation. The large openings on the right are 4½ x 4½ feet and 12 feet on centers providing adequate ventilation.

The theory of the "Magness" System is based on the fact that cold air, being heavy, will find its way through ventilator openings and drop to the floor of the storage, forcing the lighter air out through the same openings. In case the wind is blowing, faster cooling will take place as the cold air blows in on one side of the room, across the top of the fruit, and out the other side.

It is possible to combine the "Cope" and "Magness" Systems, Figure 2D. Such a type of construction gives the maximum of rapid cooling under all storage conditions, for, when the outside air is cold and immobile, it passes in through the bottom openings, up through the fruit, and out through the top openings in the walls and through the ceiling flues. Whenever the wind is blowing, the cold air enters through the side openings at the top and bottom, passes over and through the fruit containers, and out at the other side. Such a system is somewhat more expensive to construct than other types but should prove slightly more satisfactory in operation during the entire season.

[3]Magness, J. R. In a letter to the author, Jan. 17, 1933.

BELOW-GROUND, BASEMENT, AND BANK OR HILLSIDE STORAGES

The earth, when in contact with any portion of a storage, exerts a powerful effect on the air temperature within. This effect is in direct proportion to the surface area in contact with the earth and is lessened by the use of insulation. This may be an advantage or a disadvantage depending upon the temperature desired in the storage. During the summer and early fall the temperature of the earth is lower than that of the air and the soil absorbs heat and cools the storage. During the winter the soil is warmer than the air and gives up heat to the storage air (Fig. 1D). In the fall the underground storage undoubtedly maintains the fruit at a lower average and more constant temperature than is found in the above-ground type. This fact can not be overlooked and explains why many underground storages seem to keep fruit as well as the above-ground structures. The damage to the fruit wrought by high fluctuating temperatures during the early storage period is considerable and more difficult to overcome with an above-ground building. On the other hand, during the major portion of the storage period it is somewhat more difficult to maintain as low temperatures in the below-ground as in the above-ground types. Temperatures of 36 to 40° F. are automatically maintained in underground storages. However, except for certain varieties (Page 4), apples keep better at 32° F., and it is usually not difficult to maintain this temperature above ground after the first of December in Ohio.

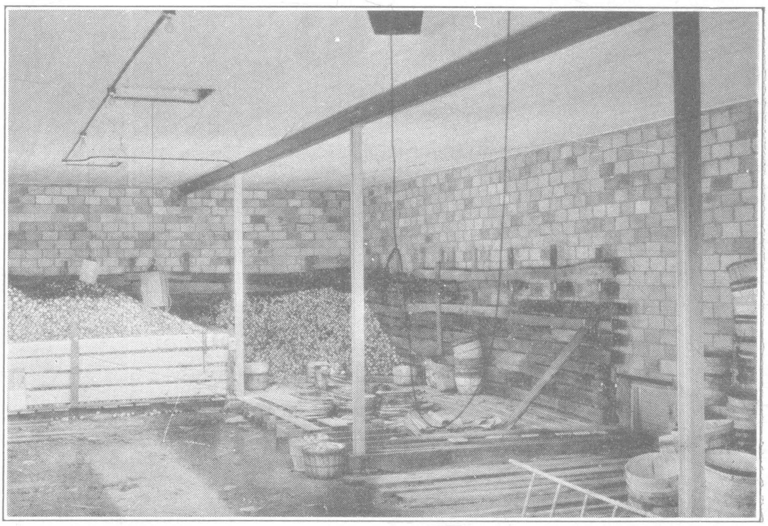


Fig. 4.—Interior of a well designed storage room

Interior view of the storage room in Figure 8. Note the absence of materials affected by moisture. Steel for columns (6) and beams (2) and tile for walls lower depreciation to a minimum. The use of steel open truss joists and rock lath covered with loose-fill insulation would still further improve this storage room. Storing apples in bulk is usually practiced only as an emergency measure.

There is some controversy as to whether the above- or below-ground type is preferable for apples. According to Magness (17), records obtained in many storages over a period of 10 years show that all types of storages hold about the same temperature if adequately insulated and properly handled. Sufficient data have not been accumulated to answer the question of the best type for Ohio. Growers in general favor the above-ground type as being satisfactory if properly constructed and managed; the cost of construction without excavating will more often be less. In Figure 5 is shown a storage constructed above ground and its walls banked with earth, a costly and unwarranted procedure. Occasionally, the basement and above-ground types have been combined into one structure with considerable success. By employing a large flue leading from the basement through the first floor and equipped with the correct dampers and a fan, it is possible to make full use of the advantages of both types through the interchange of air between the two rooms and the outside. This arrangement affords a distinct advantage, for the fruit from below may be moved into the colder upper room as the fruit is sold out of storage. Powerful exhaust fans may be installed to circulate the air between the rooms and in this way eliminate moving the fruit to the upper room until it is sold. The underground and bank storages may be left open much of the time, even in very cold weather, without freezing the fruit. This aids in maintaining low temperatures in spite of the warming effect of the earth.

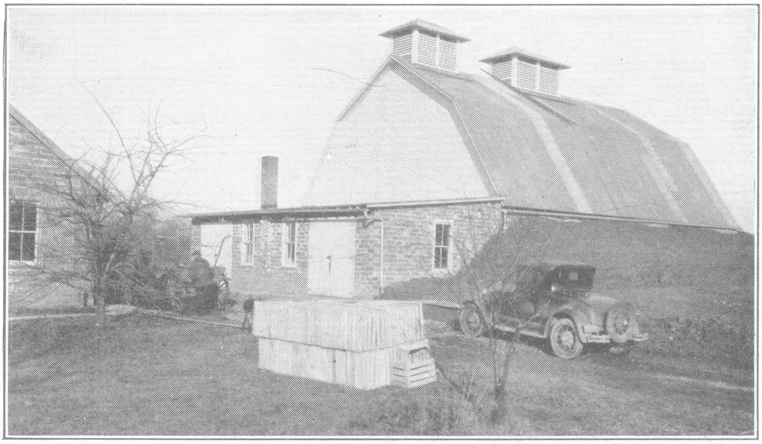


Fig. 5.—An air-cooled apple storage constructed above ground and banked with earth

This grower chose to construct solid concrete walls and depend on banked earth for insulation. The extra expense is hardly justifiable since it is more difficult to maintain low temperatures in such storages. Note the air-intake flues, the tops just showing below the roof eaves. The ventheads at the roof ridge are ample in size but due to numerous louver boards offer too great a resistance to air movement. The crate storage above is entered by truck at the rear from the ground level.

The greater the wall and roof surface exposed to the air in the underground structure, the less the temperature effect from the soil. According to Anthony (6), if the exposed walls of a bank cellar approach one-half of the total wall surface, additional heat is necessary to prevent freezing of the fruit unless the exposed walls have greater resistance to heat flow than is furnished by field stone or concrete.

It will be found, generally, that it is more economical to provide supplemental heat in the storage than to invest in sufficient insulation to prevent freezing during the very cold periods of long duration. It is neither necessary nor advisable to insulate the underground portion of a bank storage unless the greater portion of the structure is above the general ground level. Provided the only site available is in a bank, it is then advisable to construct the underground type. The question arises as to the advisability of combining the features of the two types by insulating only the half of the building above ground. The advantages of such a combination of types can best be obtained by separating the storage into two rooms with the insulated room above.

ABOVE-GROUND STORAGES

The great majority of storages in Ohio are constructed above ground. This type seems to be preferred for apples. Frequently, because of an uneven grade, the earth may be banked against the walls a foot or more above the floor level. However, the walls are insulated to the floor and the storage is considered to be above ground. Many such buildings also have the floor insulated with a foot or so of cinders beneath the concrete surface. Anthony (6) considers the earth floor valuable in heating the storage and thus assisting in the maintenance of temperatures above freezing during severe winter weather. He also considers that the control of humidity afforded by a damp earth floor is essential. On the other hand, the heat evolved from an earth floor increases the difficulty of maintaining a low temperature during the early storage period. Many growers are convinced that the advantages of an earth floor may be artificially supplied by ample insulation to prevent winter freezing and the adding of water by hose or other method to maintain a high humidity. The advantages of a concrete floor upon which to handle fruit are unquestioned, and the recent trend towards such floors in common storages suggests they are proving successful. An insulated floor of some type is essential in a refrigerated storage.

Adapting to storage use such buildings as are available on the farm is a common procedure in Ohio. The cost is low so that the storage is almost certain to prove a profitable investment for even the grower with a small acreage. It is not difficult to provide storage in this manner and such facilities will often keep fruit as well as the more costly structures.

THE STORAGE BUILDING

The fruit grower contemplating the construction of a new building for storage purposes should consider carefully the possible plans. Attention should be given to the site, size, and shape of the building and the advisability of crate storage, packing, and sales rooms under the same roof. The simple expedient of providing a small space for temporary storage or an enclosed loading platform will save much through infrequent opening of the cooler room. At present the tendency is to "dress up" the storage, for it has been found that attractive buildings and surroundings possess considerable value in promoting fruit sales.

The selection of materials and type of construction may be made with the idea of installing artificial refrigeration at some future date. This means the use of more resistant, fire-proof materials, such as tile, and the installation of conventional refrigerator doors in all openings. Additional insulation can usually be installed conveniently at some later date.

The building site for the underground type, when a choice is possible, should be in a well shaded, protected place. Trees and sod about a bank storage will aid in maintaining cool temperatures within. One of the most convenient locations for such a structure where no natural site exists is in the elevated approach to a barn. Here the barn wall serves as one wall of the storage and excavation is reduced to a minimum (12, 18).

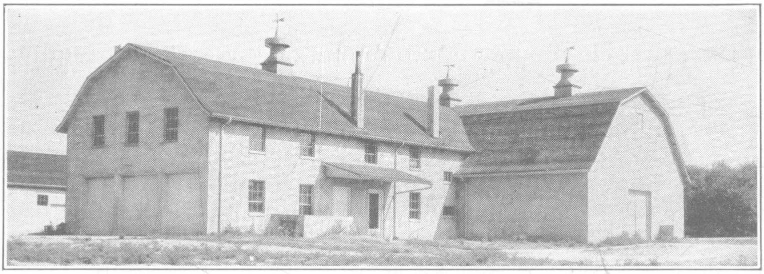


Fig. 6.—Large modern fruit packing and storage plant

Grading, packing, loading, and selling facilities are afforded, together with crate storage in the left wing and air-cooled storage on the right. Note the large doors in both wings for trucks. Artificial refrigeration was installed after a period of operation as a common storage. Capacity, 20,000 bushels.

The above-ground structure should be placed in the clear to facilitate air movement and to take full advantage of the prevailing winds. Occasionally, the topography will permit placing the building in line with the air drainage into low areas and thereby make use of this natural movement of the coldest air.

In this bulletin are shown several buildings with storage rooms giving some idea of the wide variation in plan and style. Any building approaching a cube in dimensions utilizes the minimum of construction materials per unit of storage capacity. Other factors may make it wise to select other dimensions; for example, lumber can be purchased at the lowest figure when conventional lengths are used and there is no waste in cutting. An increase in the length of timbers used, providing they are standard, may cost but slightly more; whereas such timbers will allow for a considerable increase in storage room capacity. For instance, the storage capacity of a 40 by 60-foot building may be increased equally by a 2-foot rise in height or by a 12-foot extension in length. However, the latter method would require 160 square feet less additional wall but 480 square feet more ceiling, floor, and roof area than the former, and the costs, including insulation, would be proportionally greater. Structural difficulties and expense increase, especially in the roof and supports, with wider buildings, and therefore storages are seldom constructed over 40 feet in width. The limit of height is dependent on convenience in stacking fruit, and a height of 10 to 12 feet seems to meet with the greatest favor.

With a few more facts in mind, a grower may calculate the dimensions of the storage which will accommodate his needs. Two and one-half cubic feet of storage space will be required per bushel of fruit, allowing for the necessary alleyways and space between the fruit and walls and ceiling. The capacity in bushels multiplied by 2½ gives the volume of the storage in cubic feet. This figure divided by the room height gives the floor area. This area in turn can be resolved into width and length of the room by dividing by either one value or the other. For example, a 10,000-bushel storage should contain approximately 25,000 cubic feet ($2\frac{1}{2} \times 10{,}000 = 25{,}000$). Providing the room height was to be 10 feet, the floor area would occupy 2500 square feet ($\frac{25{,}000}{10} = 2500$). Choosing a width for the building of 40 feet, the length would need to be $62\frac{1}{2}$ feet ($\frac{2500}{40} = 62\frac{1}{2}$). To simplify the calculations, use the formula $2\frac{1}{2}C/hw = L$, where C is the storage room capacity in bushels, h and w are its height and width, respectively, and L the length in feet. The height, width, and length are interchangeable in this formula, and thus any one value may be determined readily by substituting the other two in the denominator of the fraction. Substituting the above dimensions in the formula, the calculations are as follows:

$$L = \frac{2\frac{1}{2}C}{hw} = \frac{2\frac{1}{2} \times 10{,}000}{10 \times 40} = 62\frac{1}{2} \text{ feet, length}$$

$$h = \frac{2\frac{1}{2}C}{Lw} = \frac{2\frac{1}{2} \times 10{,}000}{62\frac{1}{2} \times 40} = 10 \text{ feet, height}$$

$$w = \frac{2\frac{1}{2}C}{hL} = \frac{2\frac{1}{2} \times 10{,}000}{10 \times 62\frac{1}{2}} = 40 \text{ feet, width}$$

For rapid mental calculation, five times the number of thousands of bushels to be stored will give very closely the necessary building length, assuming the standard width of 40 and height of 12 feet. A 10,000-bushel storage then would be approximately 50 feet in length ($5 \times 10 = 50$). For a 10-foot ceiling one multiplies by 6; for 14 feet, by 4.

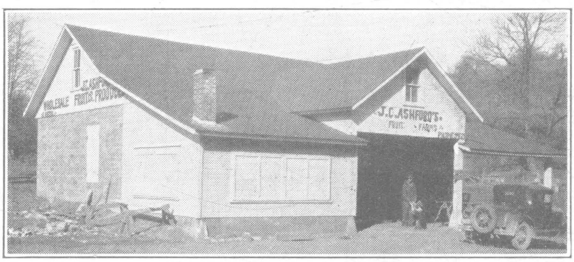


Fig. 7.—Modern example of a well planned and constructed, small, air-cooled apple storage

This storage stands a few feet from a main highway and has road-side stand and under-cover loading space, as well as ample room for grading, handling, and temporary storage; crate storage above the room in the rear. The walls consist of three air space tile laid horizontally, 2-inch air space, ½-inch board insulation, 4-inch air space, and sheathing. Intakes on two sides only. Capacity, 3000 bushels.

CONSTRUCTION MATERIALS

There are numerous building materials available for storage construction. The plan of the building will depend somewhat on the nature of the material selected. A suitable, inexpensive supply close at hand would discourage the use of other materials which might be excellent but more costly. For example, lumber from a local woodlot or tile direct from the kiln may be purchased and moved to the farm by the grower at a considerable advantage. It is frequently possible to use "seconds" in some materials with a considerable saving. For these reasons, construction materials will be discussed on the basis of their merit for use in common storages and the decision as to what should be used left to the grower.

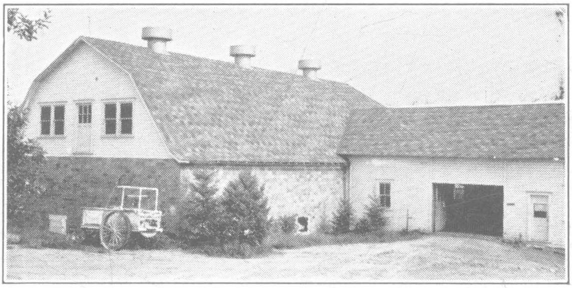


Fig. 8.—A typical, well constructed, air-cooled apple storage

This storage was constructed with the intention of adding wall insulation and installing artificial refrigeration at some later date. Notice the attached grading, packing, and sales room including truck or car storage and crate storage above the cooler room. Lumber from the farm, seconds in tile, direct buying, and trucking and overseeing by the grower kept the cost of this 12,000-bushel storage at a minimum. Built in 1931 by a grower managing 70 acres of apples, 2 of peaches, and 5 of cherries, it represents an investment of from $3500 to $4500. The storage room is 40 x 70 x 12 feet; walls are 12-inch interlocking tile (five air spaces); ceiling, 2 by 8-inch joists with one board flooring on each side and 4-inch Thermofill insulation between.

List of materials and labor for the storage shown in Figure 8:

Sawing 17,000 board feet of lumber from local woodlot	$ 140.00
Lumber purchased from local yards	502.19
Cement for foundation and part of rear wall: 30 bbl. @ $1.46	43.80
Bricks* for buttresses, rear wall, 1800 @ $16.00/M	28.80
Tile:—	
Foundation, 5 x 8 x 12 in., 1650 @ $35.43/M	58.47
Walls-Interlocking or "T" tile, seconds: 8 x 6½ x 12 in., 8900 @ $24/M	213.60
Detail block, 100 @ $100/M	10.00
Slabs, 280 @ $ 10/M	2.80
Labor on walls and foundation:—	
Mason, 432 hours @ 60¢	259.20
Helper, 381 hours @ 30¢	114.30
Contractor (erected roof, ceiling, and floor and hung doors and windows):—	
Contractor—$1.00 per hour Carpenter —$1.00 per hour Helper —$0.30 per hour	393.13
Hardware	56.87
Roof shingles, asbestos-multi. 42 squares @ $7.50	315.15
Electrical wiring:—Material	27.60
Labor	44.00
Steel:—4 – 8″ I beams, each 34½ feet 6 – 4″ I beams, columns, each 12 feet	150.00
Doors, Refrigerator:—	
10 – 24″ x 30″ for intakes @ $27.00	270.00
1 – 4′ x 6½′ cooler door @ 45.00	45.00
Freight on above	15.42
Ventilators, roof, 3-36″ @ $41.50	124.50
Insulation for ceiling, 4-inch, Thermofill, 9½ tons @ 27.42	260.50
Total	$3075.33

*M indicates one thousand.

Materials for construction may be divided into three classes: Those with structural strength only, those possessing some insulation properties in addition, and those used only as insulation. The latter are discussed under Insulation (Page 21). The first two classes overlap somewhat, since all materials possess some resistance to the flow of heat and thus insulate to a certain extent. In addition, a poor insulating material if used in sufficient thickness (usually not the most economical method) will insulate to a certain extent. The insulating value of several materials as a class and a few individually is given in Table 1.

High humidities impose severe conditions upon materials used in common storages because they tend to favor warping and disintegration of timbers and frequently encourage dry rot organisms. Buildings constructed of poor materials improperly installed may be in need of repair or rebuilding in a surprisingly short time.

Provided the question of endurance was the only consideration, all storages should be constructed with fire- and moisture-proof materials such as tile, brick, masonry, steel, etc. However, there is no question but what lumber will continue to be used to a large extent because of its many advantages. In many storages, the air circulation around the timbers is sufficient to reduce condensation and the growth of destructive organisms. During the summer, lumber will dry out and this tends to compensate for the few months when it is surrounded with moist air or is actually wet with condensed moisture. When the humidity in storages is maintained at the proper point for apples, growers will probably notice a more rapid deterioration of the unprotected lumber and insulation. As revealed through a survey of Ohio storages made in 1931, growers are inclined to allow the air surrounding the fruit to become too dry, with the result that the fruit loses water and frequently shrivels.

Local dealers are now able to obtain lumber which has received a pressure treatment with chemicals rendering the wood resistant to all forms of decay and insect injury. The additional cost for treatment is approximately 2½ cents per board foot (22). Woods possessing some natural resistance to rot are cedar, chestnut, cypress, white oak, and red wood. Fire-resistant lumber will soon be on the market according to recent reports. While treated lumber will resist destruction from dry rot or termites, the treatment affords slight protection from the absorption of moisture. Coatings of paint and similar materials greatly reduce the rate of absorption of moisture from humid air or from water but they do not prevent it, and if the exposure continues for a sufficiently long time the wood may become water soaked though painted. Plain linseed oil or oil paints brushed on lumber will fill its pores and serve to protect against rapid moisture penetration (14).

Tile, stone, brick, concrete, and other similar materials are free from the undesirable qualities just discussed and can not be too strongly recommended for use in storage construction. They are durable and fire-proof and thus reduce the fixed charges of depreciation and insurance. For above-ground buildings tile is particularly useful since it simplifies construction and, in addition, contributes more to the insulation of the structure than the other materials. The "interlocking" or "T" tile is well adapted to storage construction since walls of several widths with no through-mortar joints and several horizontal air cells may be made with one style of tile (Fig. 12, No. 25).

Steel is another material that may be used to advantage in storages. It is not affected by moisture and in the form of "I" beams supports considerable weight, thus eliminating other beams and columns. Used oil-well casings serve

TABLE 1.—Thermal Insulation or Internal Heat Resistance
Values of some proprietary and miscellaneous materials*

Material	Description	Density Lb. per cu. ft.	Conductivity per inch of thickness†	Resistance per inch of thickness†
Vacuum, high	Not practical in storages (all widths)		0.004	250.0
Air, still	No radiation or convection (all widths)		0.18	5.7
	Space ⅛ inch		0.26	3.8
	¼ inch		0.34	3.0
	½ inch		0.40	2.5
	¾ inch		1.11	0.9
Aluminum foil	Successive layers of sheet-aluminum foil, 0.0003 inch thick, spaced ⅓ inch or crumpled	3 (ounces)	0.31–0.28	3.2–3.6
Insulating blankets: Dry-Zero, Cabots Quilt, Balsam Wool, Hairinsul, Linofelt, Hair-felt, Thermofelt, or similar blankets (Range)	Hair, asbestos, grass, jute, flax, and wood fibers	1.0–17.0	0.28–0.22	3.6–4.5
Insulating loose-fills for walls: Ground Cork, Palco Bark, Rock Cork, Rock Wool, Glass Wool, Mineral Wool, Slag Wool, Sprayoflake, Wyolite, Thermofill, or similar loose-fill materials (Range)	Fibrous rock, mica, gypsum, curled pyrex, cotton silicate, slag, and wood fibers.	6.7–26.4	0.52–0.26	2.0–3.9
Insulating boards: Cork, Rock Cork, Celotex, Insulite, Maftex, Masonite, Nu-Wood, Temlock, Flaxlinum, Torfoleum, Thermosote, Maizewood, Tentest, or similar insulating boards (Range)	Licorice root, peat moss, sugar cane, flax, corn, and wood fiber pulps	10.2–17.6	0.34–0.29	2.9–3.4
Miscellaneous materials:				
Thermax	Wood chips with cement binder	26.4	0.46	2.2
Wood	Various common (average)	32.0	0.92	1.1
Charcoal	Hardwoods, coarse	13.2	0.36	2.8
Sawdust	Ideal conditions	12.8	0.41	2.4
Shavings	Planer, ideal conditions	8.8	0.41	2.4
Shavings	Ordinary, dry	13.0	0.71	1.4
Sawdust	Ordinary, dry	15.0	1.04	1.0
Brick	Old wall		0.49	2.1
Slag	Blast furnace		0.77	1.3
Cinders	Soft coal, screened		1.25	0.8
Soil	Surface of ground (for floors) any thickness		2.00	0.5
Concrete, cinder	Mostly cinders		1.94	0.5
	Few cinders		5.2	0.2
Cement mortar			2.3	0.4
Sand			2.4	0.4
Hollow tile			3.1	0.3
Concrete blocks	Dry		4.6	0.2
Limestone			5.8	0.2
Glass			5.0	0.2
Water			4.1	0.2
Concrete	Stone, wall		8.0	0.1
Sandstone			8.5	0.1
Slate			10.4	0.1
Steel			334.0	0.003
Copper			2653.0	0.0004

*The thermal insulation values given in Table 2 have been expanded in Table 1 to include a wider range of materials for purposes of comparison. Note the material classification into which the various insulants fall on the basis of heat resistance from the low density felts or blankets through the loose-fills, semi-flexible, non-rigid, and rigid boards to the materials not usually considered insulants. There is some overlapping between the classes and there are only slight differences between individual materials within these groups. Physical characteristics other than heat resistance become the important consideration in the purchase of many of the competing proprietary insulants. Data gathered from several sources, see Literature Cited.

†Thickness other than one inch is specified under the description of the material.

as columns at a very low cost. Open-web steel joists are as economical as wood, and, in addition to their long life, they possess the added advantage of allowing the crates to be stacked to the joists without cutting off air circulation. One grower constructed a very strong roof slab for an underground storage by fitting 36-inch conduit tile between the flanges of steel joists.

Fig. 9.—A well constructed, air-cooled storage room

Note the absence of wood except in the joists and ceiling. Walls are concrete, supporting columns are used oil-well casings, and the floor is earth. The intake doors (right center) are operated by rope from the center aisle. Note the generous size of the single outlet flue opening in the ceiling. Exterior view in Figure 5.

INSULATION

The purpose of insulation is to reduce the flow of heat to a minimum. Insulating against cold is the same as insulating to keep the heat in. It is not the material itself but the air it entraps that is the true insulation. All solid materials conduct heat more or less rapidly; that is, relative to still air, they are very poor insulators. Next to a vacuum, still air is the best insulator known. This accounts for the fact that any material, if properly processed, may be made into a good insulator. The lighter the material the better it will insulate, within wide limits.[4] In the more efficient insulants the raw material is processed until the number of air cells is multiplied many times and in its final form the insulation may be as much as 92 per cent "still" air. A unit volume of steel wool has a heat resistance 500 times that of an equal volume of steel.

There are other properties of good insulation materials besides resistance to heat flow which are very important and therefore certain materials are preferred to others in their manufacture. They may furnish structural strength, serve as bond for plaster, stucco, and other surfacing, or as a backing for materials such as brick veneer, shingles, and other exteriors. In this way their usefulness may be multiplied and building costs thereby reduced.

[4]The conductivity of cork (no artificial binder) varies from 0.250 at a density of 6.9 to 0.758 at 30.17 pounds per cubic foot.

TABLE 2.—Internal Heat Resistance Values of Materials*

Material	Internal heat resistance values based on sample one foot square†		
	One inch thick	Thickness commonly used or sold	
	R (Resistivity)	R (Resistance)	Thickness (Inches)
Air space, no radiation or convection (ideal condition, not found in ordinary construction)	5.70	....	....
Air space, ¾ inch (or more) wide, as commonly found in building construction	....	0.91	....
Air space with foil or fabric insulation:			
Pure aluminum metal foil			
Crumpled	2.38	....	....
Panels	2.08	....	....
Panels—3 spaces per inch	4.34	....	....
Sheet aluminum foil cemented to Kraft paper, one or both sides	2.50 5.00	....	....
Sheet aluminum foil cemented to Kraft paper corrugated and fastened with cross wires to steel ribs for plaster, stucco, and brick veneer base	2.50	....	....
Aluminum paint	0.50	....	....
Kraft paper with mineral pigment surface in center of 1-inch air space	3.03	....	....
Brick, common	0.20	0.80 1.60 2.40	4 8 12
Cinder concrete, weighing about 110 lb. per cu. ft.	0.19	1.52 1.90 2.28	8 10 12
Cinder concrete block‡	....	1.61 1.96	8 12
Concrete weighing about 150 lb. per cu. ft.	0.084	0.67 0.84 1.00	8 10 12
Concrete block‡	....	1.00 1.25	8 12
Hollow clay tile, horizontal flues‡ — 1 cell thick	....	1.00	4
2 cells thick	....	1.56	6
2 cells thick	....	1.67	8
2 cells thick	....	1.73	10
3 cells thick	....	2.50	12
Interlocking or "T" tile wall‡ 5 cells thick	....	5.00	12
Hollow gypsum tile‡	....	1.56 1.73	3 4
Insulating materials:			
Fill:			
Cork particles, 3/16 in. in diameter, weighing about 10.7 lb. per cu. ft.	3.22	11.70 18.10	3⅝ 5⅝
Wood, grass, hair, and similar fiber weighing from 6 to 13 lb. per cu. ft.	3.70	13.41 20.81	3⅝ 5⅝
Dry cellular gypsum, weighing about 18 lb. per cu. ft.	1.70	6.15 9.55	3⅝ 5⅝
Dry fluffy gypsum, weighing about 24 lb. per cu. ft.	2.08	7.55 11.70	3⅝ 5⅝
Fluffy rock, slag, or other mineral fiber, weighing about 14 lb. per cu. ft.	3.33	12.10 18.75	3⅝ 5⅝
Sawdust, dry, various kinds, weighing about 9 lb. per cu. ft.	2.44	8.85 13.70	3⅝ 5⅝
Shavings, dry from planer, weighing about 9 lb. per cu. ft.	2.44	8.85 13.70	3⅝ 5⅝
Flexible: (grass, hair, wood, and similar fiber), weighing from 2 to 13 lb. per cu. ft.	3.70	1.85 3.70	½ 1
Rigid:			
Non-structural (cork board without artificial binder or "low density" fiber boards) weighing about 10 lb. per cu. ft.	3.33	3.33 6.66	1 2
Structural (bagasse, cornstalk, straw wood, and similar fiber), weighing from 15 to 19 lb. per cu. ft.	3.03	1.51 3.03	½ 1
Semirigid (grass, flax, and similar fiber), weighing about 13 lb. per cu. ft.	3.12	1.56 3.12	½ 1

TABLE 2.—Internal Heat Resistance Values of Materials*—Continued

Material	Internal heat resistance values based on sample one foot square†		
	One inch thick	Thickness commonly used or sold	
	R (Resistivity)	R (Resistance)	Thickness (Inches)
Plaster, gypsum	0.30	0.15	½
Plaster board	...	0.27 0.35	⅜ ½
Plaster and metal lath	...	0.23	¾
Plaster and wood lath	...	0.40	¾
Roofing, asbestos or composition	...	0.15	...
Shingles:			
Asbestos	...	0.17	...
Slate	...	0.10	...
Wood	...	0.78	...
Surface resistance:			
Inside, still air (representative value for common building materials)	...	0.60	...
Outside, 15 mi. per hr. wind velocity (representative value for common building materials)	...	0.17	...
Stone	0.08	0.96 1.28 1.60	12 16 20
Stucco	0.084	0.063 0.084	¾ 1
Wood:			
Weighing 20 to 25 lb. per cu. ft. at 12% moisture content. Western red cedar, northern white pine, sugar pine, and Englemann spruce	1.43	0.80 1.07 1.13 2.33	9/16§ ¾‖ 1** 2***
Weighing 26 to 35 lb. per cu. ft. at 12% moisture content. Red cypress, Douglas fir, white fir, Idaho white pine, ponderosa pine, redwood, and spruce	1.25	0.70 0.94 0.98 2.04	9/16§ ¾‖ 1** 2***
Weighing 36 to 45 lb. per cu. ft. at 12% moisture content. Western larch, tamarack, soft pine, long leaf pine, short leaf pine, and Carolina pine	1.00	0.56 0.75 0.78 1.63	9/16§ ¾‖ 1** 2***

*Adapted from the twenty-fifth report of the National Committee on Wood Utilization, Department of Commerce, U. S. A.

†Internal resistance represents the degrees difference in temperature on opposite surfaces of a material 1 inch thick (resistivity) or thickness as stated (resistance) which will cause 1 B. t. u. of heat to pass through an area 1 square foot in 1 hour. Conductivity and conductance are the reciprocals of resistivity and resistance, and therefore either may be used in calculations of thermal heat resistance or conductance. The amount of heat transferred through a material in 1 hour equals $CA\ (t_1\text{-}t_2)$, which also equals $\frac{A\ (t_1\text{-}t_2)}{R}$, where C is conductance per unit area, R resistance, A area in square feet, t_1 the inside surface temperature, and t_2 the outside surface temperature.

‡Estimated from an air space conductance of 1.0, any thickness; conductivity of burned clay 5.0, concrete 8.3, cinder concrete 3.33, and gypsum tile 1.66 per 1 inch. Load-bearing tile walls ¾ inch, webs ⅝ inch, all other tile ⅝ and ½ inch, respectively. Concrete block shells and webs 2 inches thick. Gypsum tile; 3 x 12 and 4 x 12, 3 inch has 4 cores per 12 inches, each 1¾ inch diameter; 4 inch has 3 cores per 12 inches, each 2½ inch diameter. The resistance of hollow masonry units also includes the value of the air spaces in the unit; all other resistances shown are for the materials themselves.

§Ceiling, actual thickness.

‖Drop siding, actual thickness.

**Sheathing or flooring (surfaced two sides, actual thickness 25/32 inch).

***Lumber (surfaced two sides, actual thickness 1⅝ inches).

Many materials, if used in sufficient thickness, may provide considerable resistance to the flow of heat, but it is always more economical to employ a substance specially processed to resist heat flow, with the exception of a few such as shavings, sawdust, etc.

Commercial insulating materials may be divided into three general groups: (a) fibrous materials either in loose form or fabricated into soft flexible quilts confined between relatively thin layers of paper or textile, (b) more or less rigid boards in which the components are bonded together in some way, and (c) fabric or foil insulation coated with minerals, metal oxides, or made of pure aluminum, Table 2. The differences in respective insulating values of materials within each group are usually so small that they may be neglected by the grower, and for this reason they have been handled in groups in Table 1.

In order to calculate and compare the insulation values of materials and finished walls, one must understand the term "thermal conductivity", which is the rate at which heat will pass through a body when one side is exposed to a lower temperature than the other. A knowledge of the mechanism of heat transfer is essential to this understanding but a detailed study of this subject is not necessary. The three major methods of heat transfer are conduction, convection, and radiation. Heat always flows from a warmer to a cooler body; in other words, the direction of heat flow is always from the higher to the lower temperature or, as with water, down hill. Conduction alone is of importance in the flow of heat through insulation and other materials. This "yard stick" for measuring the flow of heat through materials (i. e., the "thermal conductivity") is expressed in British thermal units (B. t. u.). One B. t. u. is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. This applies regardless of the period of time necessary to raise the temperature of the water one degree. Therefore, the element of time must be included in measurements of heat flow, as well as the unit of area of the exposure and the thickness of the material through which the heat flows. Consequently, thermal conductivity or k is usually expressed as B. t. u. flowing per square foot per inch of thickness per degree Fahrenheit difference in temperature on the opposite sides per hour and may be abbreviated to B. t. u./ft.^{2}/inch/°F./hr. It is frequently convenient to use another value in heat flow calculations, which is termed resistance or R. Since it is merely the reciprocal (1/k) of conductivity (actually conductance[5]), it may be defined as the degrees difference in temperature on opposite surfaces of a material 1 inch thick which will cause 1 B. t. u. of heat to pass through an area of 1 square foot in 1 hour. Resistance values for several materials may be added to give a total resistance which can not be secured by using conductivity values alone.

As will be shown, the insulating value of a wall is equal to the sum of the resistances of the respective layers of material in that wall and the calculation is analogous to adding the several resistances in a water system to determine the total resistance and water flow in that system. Also, the relative thermal value of two walls is directly proportional to their total resistances.

[5]The reciprocals of "conductivity" (k) and "conductance" (C) are "resistivity" and "resistance", respectively. "Resistivity" values represent the degrees difference in temperature on opposite surfaces of a material 1 inch thick which will cause 1 B. t. u. to pass through an area of 1 square foot in 1 hour; "resistance" values are the same for a stated thickness rather than for 1 inch. "Conductance" per unit area is frequently termed the "heat-transfer coefficient", the symbol being *C*. This value is used to determine the quantity of heat flowing through walls, floor, and ceiling of storages and may be used to determine the refrigeration required to counteract this heat. For example, the heat passing through a wall per hour is equal to AC $(t_1\text{-}t_2)$ where *A* is the number of square feet of wall surface; *C*, the heat-transfer coefficient; t_2, the temperature of outer wall; t_1, the temperature of inner wall. Resistance values instead of conductance values may also be conveniently used (resistances and conductances are reciprocals) to determine the amount of heat transmitted through a material, for the above formula also equals $\frac{A\ (t_1\text{-}t_2)}{R}$, where *R* is resistance and the other values are the same.

Examples will make clear the meaning and use of the above terms. It is first necessary to discuss thermal resistance of air spaces and surfaces. Air is a very poor conductor of heat, but, on account of the large transfer of heat by convection and radiation within an ordinary air space found in frame walls, the effectiveness of such spaces is quite small. According to the United States Bureau of Standards and contrary to popular belief, from 50 to 80 per cent of the heat transfer across air spaces in walls takes place by radiation (21). If it were feasible to bound air spaces by bright metallic surfaces (as in thermos bottles, aluminum-foil insulated refrigerators, and walls containing mineral-impregnated fabric), the heat transfer across such air spaces could be greatly diminished, through the reflection of heat rays similar to the reflection of light rays by the same surfaces. This method is being employed in some storages at the present time.

The insulating value of an air space is not proportional to its width (thickness) and varies considerably with both mean temperature and temperature difference due to the large effects of radiation and convection. For spaces more than about ¾ inch wide, the insulating value is practically constant and independent of width. Narrower spaces have less insulating value and below about ½ inch it is approximately proportional to the width, Table 1. Under average conditions the conductance of the vertical air spaces commonly found in storages is about 1 B. t. u. per square foot per degree F. per hour. This corresponds to from ¼ to ⅓ inch thickness of average insulating material (Table 2).

All surfaces have adhering to them a thin layer of "still" air. The thickness of the layer depends upon the type of surface and upon the speed with which air is moving across it. The resistance afforded by such thin air films is known as "surface resistance". When the air is disturbed as by wind, the surface air film becomes thinner and consequently offers less resistance to the escape or entrance of heat by conduction. Average values for the two surface resistances are given in Table 2. The resistances of interior surfaces of walls are included in the resistance of such air spaces as occur there.

To determine the total thermal resistance of a wall, the conductivity value (k) or its reciprocal resistivity (R) (Column 1 in Table 2) of each material in the wall must be known. From either one or the other of these values the resistance of each material in the thickness used may be calculated, and by adding these values the total wall resistance is obtained.

An example will make clear the method.[6] The total insulating value of a frame wall consisting of 2-inch by 4-inch studs with 1-inch wood sheathing, building paper, and ¾-inch drop siding on the outside and 1-inch matched lumber on the inside is as follows (Table 2):

¾-inch drop siding	0.94
Building paper (no internal insulating value but useful in stopping air leakage)	0.00
1-inch wood sheathing	0.98
Air space between inside and outside sheathing	0.91
1-inch matched lumber	0.98
Inside surface	0.60
Outside surface	0.17
Total insulating value of wall	4.58

[6]Taken from the 25th report of the National Committee on Wood Utilization.

If flexible insulation ½ inch thick is placed in the space between studs, leaving an air space on each side of the insulation, the figures would be:

Wall without insulation	4.58
One additional air space between insulation and sheathing[7]	0.91
½-inch flexible insulation	1.85
Total insulating value of new wall	7.34

The insulated wall will, therefore, resist the passage of heat approximately 1.6 times (7.34 divided by 4.58) as well as the non-insulated wall, since the relative value of the two walls is directly proportional to their total resistances.

INSULATING MATERIALS

The conductivities of most materials sold primarily as insulation fall within the range 0.25 to 0.35 B. t. u./ft.²/inch/°F./hr. (resistances 2.85 to 4.00, and less than 1½ inches of the poorest material is equivalent in insulating value to 1 inch of the best. The heat conductivity of the ideal insulation (air, $k = 0.175$ B. t. u./ft.²/inch/hr./°F.) is only slightly less than the better commercial materials (Table 1).

With the existence of such small differences among good insulants, their remaining properties become of greater importance in making a selection. In Table 1 are given the thermal values for some specific commercial materials employed in storage construction and a few additional materials which are interesting for purposes of comparison. Some of the desirable characteristics and properties to be looked for in these materials are as follows:

1. Low thermal conductivity (high thermal resistance).
2. Full thickness as advertized.
3. Proof against air infiltration when applied.
4. Proof against moisture absorption when applied.
5. Definite and constant density when applied.
6. Permanent and durable.
7. Easy to handle and apply.
8. Fire retardent.
9. Repellent towards vermin, rodents, and rot organisms.
10. Non-odorous.
11. Useful as structural material to replace lumber.
12. High adaptability for all types of construction.

There are times when a low heat conductivity and a high durability in a material are sufficient to make it very useful for insulation only in a double wall such as tile. Blanket and some semi-flexible forms of insulation, since they are installed (flanged) midway between the framing members (studs or joists), have their insulating value increased by an amount equal to the resistance of the extra air space created. When using ½ inch of the above insulation, the extra air space increases the heat resistance from 40 to 60 per cent at no extra cost.

The real cost of an insulating material is not the cost per square foot of commercial thickness but rather the cost per unit insulating value of the commercial thickness. This fact is frequently overlooked and can not be emphasized too strongly. In many cases the cost on an "installed" basis will be comparable to the cost on the "material alone" basis, but in other cases there would undoubtedly be considerable difference.

[7]Two air spaces instead of one, though each be smaller, have twice the insulating value of the single space

Examples will make clear the methods of comparing insulation. A common flexible type of insulation has a thermal conductivity of 0.246 and a resistance of 4.065 ($\frac{1}{0.246} = 4.065$). For a good board type of insulation the values are: conductivity, 0.330 and resistance, 3.03. The flexible insulation will resist the passage of heat approximately 1.34 times ($\frac{4.065}{3.030} = 1.34$) as well as the board insulation. Expressed as efficiency, the flexible type is 34.1 per cent ($\frac{0.330\text{-}0.246}{0.246} \times 100 = 34.1$) more efficient than the board type, or, stated as the reverse, the board insulation is only 74.5 per cent ($\frac{0.246}{0.330} \times 100 = 74.5$) as efficient as the flexible material.

Providing the two types of insulation were of equal thickness and cost the same (1 inch thick, cost, 5 cents per square foot), their value as insulation should be reckoned in terms of the cost per unit of insulating value or thermal resistance. The total cost per square foot divided by the thermal resistance shows the board material to cost 1.65 cents ($\frac{0.05}{3.03} \times 100 = 1.65$) per unit of resistance or 34 per cent ($\frac{0.05}{4.06} \times 100=1.23$) ($\frac{1.65 \; - \; 1.23}{1.23} \times 100=34.1$) more than the flexible insulation.

As frequently occurs, an insulant with a commercial or normal thickness of 1 inch may have an actual thickness of 1⅛ inches. Thickness and prices obtained at a local lumber yard showed a good flexible insulation to be 1⅛ inches in thickness and to cost 4½ cents per square foot. A good board insulation measured 1 inch in thickness and cost 5 cents per square foot. Recalculating the cost per unit of thermal resistance for these two materials, one finds that the flexible insulation cost slightly less than 1 cent (0.98 cent) per thermal unit while the board insulation cost 1.65 cents for the same resistance. In this specific case the flexible material cost 10 per cent less on a square foot basis and 41 per cent less on a basis of thermal units of resistance received.

Board insulation is usually not placed between studs in a wall while the flexible types are flanged midway between the framing members and thus the insulating value of the wall is increased by an amount equal to the resistance of the extra air space created ($R = 0.91$). Thus, the cost per unit of thermal resistance of a wall may be reduced by from 10 to 50 per cent (depending on the total resistance of the wall before applying the insulation and the thickness and resistance of the insulation employed) at no additional cost since the newer flexible materials are installed at approximately the same cost as board insulants.

Notice also that when insulation board replaces sheathing, the insulation is costing nothing (the cost of the two materials installed is approximately the same). It is possible for the cost per unit of thermal resistance of the same wall with sheathing and a blanket or flexible insulation to be actually less than the board-insulated wall due largely to the value of the additional air space created. For these reasons it is unsafe to evaluate insulation otherwise than on an installed basis and this necessarily takes into consideration the cost of the entire wall.

The type of insulation used will depend upon the specific requirements and the over-all cost of the wall. It would obviously be poor economy to use an insulant with a low cost per unit of thermal resistance providing the material had poor physical properties, was very costly to install, or, in the case of some loose-fill materials, required an excessive thickness to fill the air space in the wall.

Two factors in the selection of insulation which are undoubtedly of the greatest importance are air infiltration and moisture penetration. Unless the insulation is airproof it is never waterproof. Many insulating materials will not absorb water from other materials nor have they any capillary attraction for water; however, they will readily become moist and thus useless as insulation if moisture-carrying air can penetrate, since at some place in a storage wall the temperature is usually sufficiently low to cause condensation of moisture out of the air. Where moisture is present, rot organisms can thrive if an acceptable food is present. The newer insulation now offered on the market is airsealed in some manner, such as enveloped in airproof and waterproof paper or coated with an asphaltic compound. Loose-fills are now correctly built into a wall coated with asphaltic paint or lined with resistant paper. Experiments under severe conditions have shown that insulation sealed in waterproof paper or impregnated with substances reducing moisture absorption may still absorb 20 per cent (by weight) of moisture and thereby lose 7 per cent of its insulating value.[8] It should never be inferred from statements concerning the value of airproofing insulation that moisture may be entirely excluded from any material. Humidity in the air functions as a true gas subject to its individual pressure. At the moment a difference in temperature exists between the inside of a wall or insulant and its exterior, the partial pressure of the water vapor (in the form of a gas, not minute water droplets) inside and outside that material also changes, and as a result the gaseous water moves into the wall and insulant. This gaseous water is nearly four times as penetrative as an air mixture (minute water droplets in air) and its penetration cannot possibly be prevented unless a partial vacuum can be maintained indefinitely and this is clearly impossible with the best methods of sealing walls or insulation.[9] Air infiltration may be 20,000 times greater for unprotected fill materials than for the same insulation sealed in paper. The value of airsealing insulation, walls, and particularly the outside of a storage wall cannot be overemphasized. The value of various materials to prevent air infiltration may be gathered from Table 3. Means for protection of the outside against air infiltration are always needed, for water-air mixtures may penetrate materials repellent to the liquid alone. The real factor responsible for moisture movement through any wall is the difference in vapor pressure existing. The most common condition is a higher temperature and vapor pressure outside so that an outside seal is the most effective, although not a complete seal.

Ordinary waterproof papers are of more value in excluding air-water mixtures if they are asphalt coated and sealed with hot asphalt at all joints.

Most insulating materials are either naturally resistant towards vermin, rodents, and rot organisms or may be made so by chemicals, such as sodium

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[8]Data supplied by the Wood Conversion Co., Cloquet, Minnesota.

[9]Information supplied through correspondence with the author by H. B. Lindsay, President, Dry-zero Corporation.

fluoride.[10] Likewise, if a material is not naturally fire retardent, the use of ammonium sulfate will eliminate this hazard.[11]

There is some misconception by many fruit growers concerning the insulating value of such materials as building paper, heavy wall boards containing plaster, stone and concrete, and many others. Papers are excellent in preventing air infiltration and therefore should be used freely in apple storage houses. It is not feasible, however, to eliminate any insulation by the use of paper for it would require 95 layers of paper (0.025 inch per sheet) to equal ½ inch of good insulation. It would require approximately 9 inches of gypsum plaster, 20 inches of brick, 33 inches of concrete (1:2:4 mix), and 40 inches of stone to be equivalent in insulating value to one inch of some good commercial insulation. If the insulation were flanged between studs or joists to create an additional air space, these figures would be increased by 30 per cent.

TABLE 3.—Infiltration of Air*

Material	Thickness In.	Air infiltration ft.^{3}/hr./ft.^{2} at 40 lb./ft.^{2} (90 miles per hour)
Beaver board	0.182	0.593
Balsam wool	0.807	0.27
Pressed wood fiber boards	0.166	34 to 43
Average of seven representative insulating boards	0.417 to 0.535	174.0
Cork board	1.513	432.0
Duplex Kraft paper	0.0065	0.0
Kraft paper coated one side with asphalt	0.0100	0.00–0.057
Asphalt, one coat	0.0200	0.00
Aluminum foil	0.0006	0.00

*Selected data from George, L. P., in "Refrigerating Engineering", Vol. 23, March, 1932. The American Society of Refrigerating Engineers, 37 West 39th St., New York, N. Y.

It frequently happens that various materials are available locally or at a very low cost which might be used as insulation. The question arises as to the usefulness of sawdust, planer shavings, ground charcoal, cinders, slag, straw, grain chaff, and hulls. Tests show the thermal resistance of these materials to be about as high as some commercial insulants. Oats at various moisture contents have a thermal resistance per inch thickness of from 1.5 to 2.5. The average value for planer shavings and sawdust is 2.0 and for cinders 0.8. Many of these materials absorb moisture very readily, and in some cases it is almost impossible to keep them dry in a wall. On the other hand, the more dense materials, such as sawdust and shavings, when properly installed between paper in a wall will serve very well as insulation. These materials

[10]The moisture contained in wood fiber material in per cent of weight when dry may vary from 0 to 100, which increases the conductivity from 0.294 to 0.560.

In relative humidities of 25, 50, 75, and 100 per cent, wood (average of several common types) will absorb moisture to the extent of 6.2, 9.0, 12.9, and 23.5 per cent of its dry weight, respectively. For cork, the percentages are 2.4, 3.1, 8.2, and 20.0; for charcoal, 2.4, 6.4, 9.3, and 9.6; for glass wool, 0.1, 0.2, 0.3, and 0.6, respectively. Food Investigation Board, Special Report No. 35, p. 75.

[11]Ammonium sulfate is a stable chemical, which decomposes only at 500° F. (boiling point), at which temperature ammonia gas is released, thus excluding oxygen and retarding if not eliminating combustion. This salt weighs approximately 9 pounds per cubic foot and should be incorporated with loose-fill insulation materials at the rate of 10 per cent by weight or 2 per cent by volume.

Sodium fluoride has a fungicidal action and is distasteful to rodents and, when mixed in the proportion of 2 pounds of salt to 100 pounds of dry insulation material, will protect against destruction by dry rot and other organisms. The mixing should be thorough, and it is well to dampen the insulation somewhat to aid in holding the fine powder and prevent the material escaping as a fine dust. Sodium fluoride is poisonous if taken into the eyes, nose, or mouth in sufficient quantities. Correspondence with G. M. Hunt, Forest Products Laboratory, U. S. Forest Service, Madison, Wisconsin, Aug. 15, 1933.

are not processed to resist rotting and, unless treated with sodium fluoride, they may be destroyed in a short time. Cinders and slag are examples of materials which are resistant to deterioration but have such low thermal values they must be used only in very thick walls to obtain ample protection. Such materials should be used only where their low cost (installed) is the deciding factor and then only after they are well dried and properly sealed in the wall.

CONSTRUCTING THE STORAGE

THE FLOOR

The type of floor in a common storage is not of great importance since it has been found by experience that fruit keeps well on concrete or earth, provided the relative humidity is maintained at 85 per cent or above. An earth floor aids in maintaining the humidity in proportion to its natural dampness, which in turn depends upon the soil type and underlying strata. For example, an occasional storage floor may be on moisture-bearing rock which is damp at all times without being muddy. On the other hand, many locations are on sand or a loose soil well drained where capillary movement of water is poor and little or no moisture reaches the surface. It is frequently necessary to wet down an earth floor, and in the case of concrete floors all the water must be supplied artificially. The earth floor has the added advantage of cooling the storage during early fall and spring and aids in maintaining the temperature above freezing in the middle of the winter. On the other hand, during the major portion of the storage period the earth temperature is higher than the average outdoor air temperature and thus tends to warm unduly the storage air and to increase the difficulty of keeping the temperature down, Figure 1D.

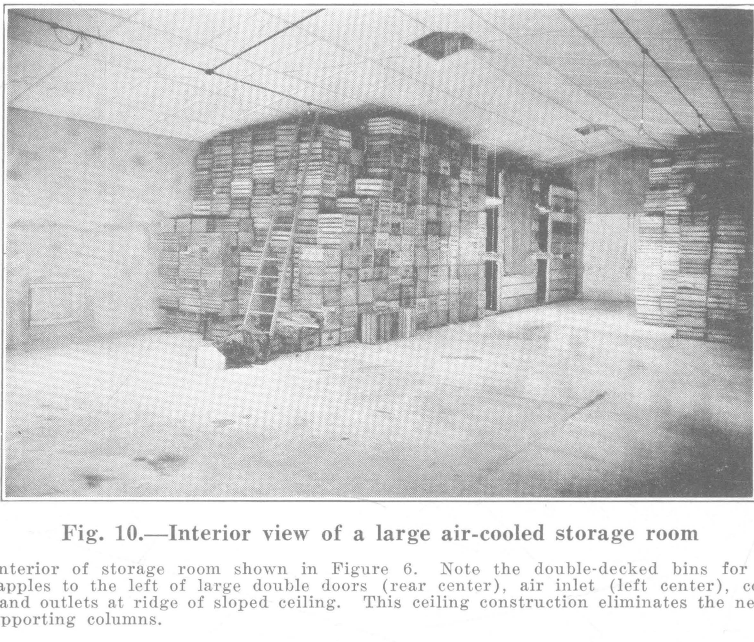


Fig. 10.—Interior view of a large air-cooled storage room

Interior of storage room shown in Figure 6. Note the double-decked bins for excess bulk apples to the left of large double doors (rear center), air inlet (left center), concrete floor, and outlets at ridge of sloped ceiling. This ceiling construction eliminates the necessity for supporting columns.

Heat flows rapidly through earth (a conductivity of 2.00 is accepted for earth floors) and thus earth cannot be considered insulation in any sense. Many growers who have experienced difficulty in cooling their storages are considering the advisability of excluding the heat of the earth floor by the use of 12 to 24 inches of fine cinders (from a 2-inch screen) covered with a layer of concrete. Such a floor aids in the handling and stacking of the fruit, is easily kept clean, and may be sprinkled with water when the storage air becomes too dry. False floors are no longer considered essential in getting the cold air to the lower layers of fruit, and where they are useful over rough, damp, dirt floors, any scrap lumber placed on tile, brick, or concrete blocks laid on the floor will be found adequate and much less costly. As an aid in maintaining a favorable air humidity, a highly absorptive surface as loosely laid porous brick, slag, or sand will be found useful.

WALL CONSTRUCTION

There is no best material or method of wall construction. There are many storages in Ohio with quite dissimilar walls; yet many of them give similar results at practically the same cost. The main requirements are that the fruit shall be kept from freezing during extended cold periods, air infiltration shall be at a minimum, and the materials used should be fairly waterproof.

Glazed or cement-coated tile walls meet these requirements and are therefore highly recommended. Lumber used alone, aside from being expensive, will absorb considerable moisture from the high humidity atmosphere; this leads to warping, molding, and decay. All of the heavy building materials, like masonry and concrete, are very good conductors of heat and are therefore not regarded as the most satisfactory materials for wall construction, except as a base for insulation.

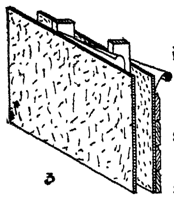
It is rather difficult to suggest the total thermal resistance required in a wall to protect the stored fruit from too low temperatures under all conditions. When the storage is full there is less danger from freezing than when it is half full. The duration of the extreme cold period is also a factor concerned with the danger of losing fruit by freezing.

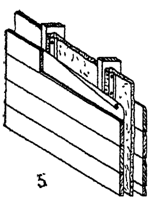
Doubling the amount of insulation in a wall will not reduce the cold penetration by one-half since the value of any added insulation depends upon the thermal resistance of the original wall. For this reason it is usually more economical to provide a small amount of artificial heat in the storage during extended periods of exceptionally severe weather or when there is only a small amount of fruit in storage than to provide an excessive thickness of insulation to protect the fruit during these periods.

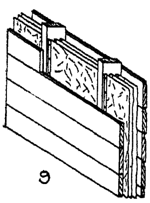
Based on the experience of many growers in Ohio and Michigan, the equivalent of 1½ inches of good insulation, such as corkboard, may be considered the minimum for common storage construction. Such a wall would have a thermal resistance of five, which is about that provided by a 12-inch interlocking or "T" tile wall with five horizontal air cells. Storages provided with walls of a total resistance of five or less would not be expected to maintain quite as uniform temperatures in the fall when outdoor temperatures are quite variable, and for this reason it is more common to provide walls with insulation equivalent to from 2 to 3 inches of corkboard (thermal resistance 6 to 10), Figures 11 and 12.

INSULATING VALUES OF SOME WALL CONSTRUCTIONS

No. **Construction** **Insulating value**







1. ¾-in. drop siding, paper, 1-in. wood sheathing, studs, paper, 1-in. matched lumber.

2. Same as No. 1, except 1-in. insulating board replaces sheathing

3. Same as No. 2, except 1-in insulating board replaces matched lumber.

4. ¾-in. drop siding, paper, ½-in. insulating board, furring strips, ½-in. insulating board, furring strips, ½-in. insulating board, paper, studs, paper, 1-in. insulating board.

5. ¾-in. drop siding, paper, studs, 1-in. semi-rigid insulation midway in stud space, paper, 1-in. matched lumber

6. Same as No 5, except 1-in. flexible insulation replaces semi-rigid insulation.

7. Same as No. 3, except 1-in. flexible insulation added midway in stud space.

8. Same as No. 5, except two layers Silvercote fabric insulation added in stud space.

9. Same as No. 8, except three layers fabric insulation.

10. Same as No. 3, except ⅜-in. Silvercote insulation coreboard replaces 1-in. insulation board used. Furring between drop siding and insulation.

11. ¾-in. drop siding, paper, 2x4-in studs, paper, 1-in. matched boards, stud space filled with 3/16-in. cork particles.

12. Same as No. 11, except dry fluffy Gypsum fill insulation used.

13. Same as No. 11, except rock or mineral fiber fill insulation used.

14. Same as No 11, except dry shavings fill insulation used.

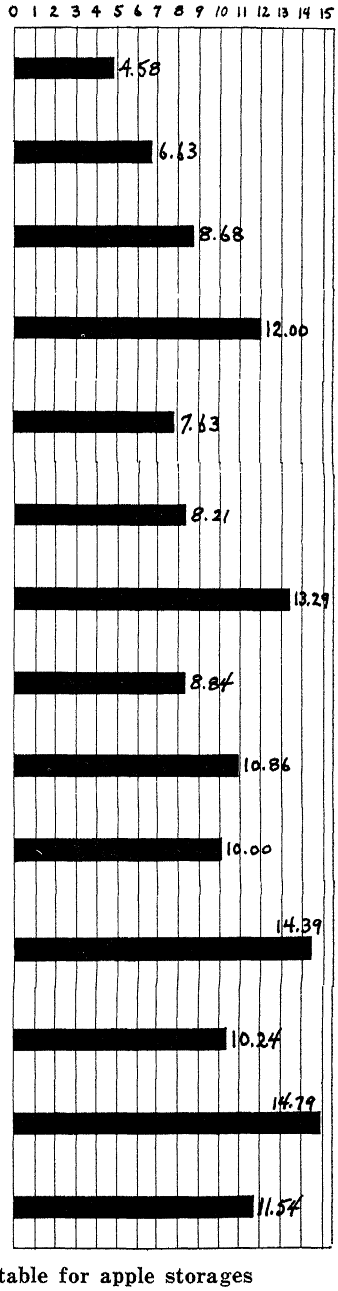


Fig. 11.—Some frame constructions suitable for apple storages

The sectional drawings are each representative of one method of construction using a given type of insulation.

Similar walls with slight modifications are also described and their insulating value (over-all resistance) represented on a graph for easy comparison. Method of presentation adapted from the 25th report of the National Committee on Wood Utilization, U. S. Department of Commerce.

INSULATING VALUES OF SOME WALL CONSTRUCTIONS

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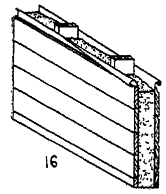

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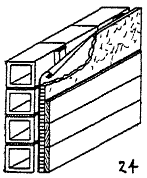

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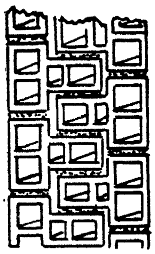

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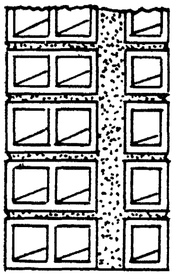

No.	Construction	Insulating value
15.	Same as No. 11, except soft coal-screened cinder fill insulation used.	7.69
16.	Same as No. 11, except expanded Mica fill insulation used.	11.44
17.	Same as No. 11, except shredded Red Wood bark fill insulation.	16.75
18.	8-in concrete.	1.44
19.	16-in. stone.	2.05
20.	8-in. concrete block.	1.77
21.	8-in cinder concrete block.	2.38
22.	8-in. cinder concrete block, furring strips, 1-in. insulating board, 9/16-in. ceiling.	7.02
23.	8-in. hollow tile.	2.44
24.	8-in. hollow tile, furring strips, 1-in. insulating board, 9/16-in. ceiling.	7.08
25.	12-in. hollow interlocking tile.	5.00
26.	12-in. glazed tile, 2-in. ground cork, 4-in. glazed tile.	10.71
27.	8-in. brick.	2.37
28.	14-in. brick laid on edge, 1-in. flexible insulation midway in wall space.	7.00

Fig. 12.—Some masonry constructions suitable for apple storages

The sectional drawings are each representative of one method of construction using a given type of insulation or no insulation. Similar walls with slight modifications are also described and their insulating value (over-all resistance) represented on a graph for easy comparison.

In Figures 11 and 12 are presented several typical storage walls including most of the types encountered in Ohio. The graphical representation of the total thermal resistance of these walls aids in their rapid comparison with one another and with the standards just described. The perspective drawings indicate how each typical wall is constructed and with only minor variations would represent the remainder of the walls described.

When convenient, it is always well to separate layers of insulation by means of furring strips, since each additional air space created in a wall is equivalent to from ¼ to ⅓ inch more insulation. Stated in another way, the addition of a ½-inch layer of insulation in the middle of an air space is the equivalent of adding a little more than ¾ inch at some other place in the wall. The added cost of this type of construction must be considered, for practically the same results may be obtained more economically by replacing the regular sheathing with a good board insulation. In case additional insulation is required, one of the flexible or semi-flexible forms flanged midway between the studs might prove the most economical.

No additional insulation is required where the space between the studs is filled with a loose-fill type of insulation. A combination of board and fill forms of insulation will provide the maximum thermal resistance without the use of additional layers of material separated by furring strips. The more recent process of coating board insulation with a highly reflective surface offers possibilities for cheaper insulation since the cost per unit of thermal resistance is lowered by this method. The same surface on a good grade of waterproof paper provides considerable resistance to the flow of heat at a moderate cost and at the same time is unaffected by moisture and effectively airseals the wall. At present only limited experience with this type of insulation in common storages is available. All reflective types of insulation should be thoroughly investigated as they may prove of considerable value for some types of construction.

Masonry walls must be insulated with one or more layers of insulation placed on furring strips, or studding must be erected and loose-fill insulation placed in this frame wall. Tile walls usually require somewhat less additional insulation and may be erected with interlocking or "T" tile to require no further insulation. This type of wall also has discontinuous mortar joints which are essential to reduce moisture and heat penetration. Tile and masonry walls possess several advantages over frame construction; i. e., they are economical, fire-, rodent-, and waterproof (or may be made waterproof), and usually provide several air spaces. Double tile walls with insulation between, well sealed against air and moisture penetration, are highly recommended as fulfilling the requirements for common storage construction.

All storage walls should be airproofed on both surfaces wherever possible. Few growers fully realize how important it is to make every effort to protect the materials in a wall, especially insulation, from moisture penetration which invariably reduces the wall efficiency and frequently causes its deterioration. Although it is seldom done, there is no treatment superior to coating a wall surface with some asphaltic compound. If the black color of the finish is objectionable, a small amount of aluminum dust mixed with the asphaltum will eliminate this objection and may even increase the efficiency by reflecting more of the heat. This treatment is particularly applicable to unglazed or soft tile, such as the interlocking tile walls. Asphaltic paints which may be brushed on cold are now available. Preparations containing pitch or tar, such as roofing paints, are not usually recommended because of the danger of the fruit absorbing the objectionable odor. Covering such paints with a coat of asphalt seems to mask or entirely destroy the tar odor and such paints have been used in this manner with success. The waterproof plasters or stuccos used on soft tile should be airproofed with these preparations, for they are somewhat porous and air will penetrate where free moisture will not.

Wood, presswood, and other slightly porous materials may be partially waterproofed by means of two coats of a good oil paint or linseed oil alone, applied when the material is thoroughly dry. No coating for wood or insulation, with the possible exception of asphalt, is yet known that will prevent moisture absorption. However, paints and oils greatly reduce moisture absorption and for this reason should be used as partial protection. In addition, well lapped waterproof paper should be used freely, especially in frame walls, to protect all insulation. The fiber boards may be protected with paint to some extent, but unless the loose-fills are lined on both sides with paper they will soon lose their efficiency through the deposition of moisture carried by air infiltration. The moisture penetrating as a gas by diffusion can not be excluded by any practical means.

CEILING CONSTRUCTION

It seems advisable to construct sufficiently high walls so that the flooring over the top of the joists will be flush with the top of the wall. If this is not done some additional precautions must be taken to prevent frost entrance at the junction of the wall and ceiling. Insulation is best placed between or over the tops of the joists. If placed beneath the joists, insulation is likely to warp, and therefore lath and cement plaster (1 part cement to 2 parts sand) or other waterproof material should be used there instead. The use of flexible board or loose-fill insulation in the ceiling is no different from its use in a wall. By separating layers of insulation or boards and by the use of paper, the maximum insulating effect is obtained. Loose-fill materials are likely to prove economical and effective since they are easily applied and have more opportunity to dry out through air circulation than when sealed in a wall. Since the warmest air is always at the ceiling, the greatest heat losses or cold penetration take place at the wall-ceiling junction and through the ceiling itself. For this reason extra precautions and thickness of insulation should be used in constructing this portion of the storage.

MISCELLANEOUS CONSTRUCTION

Doors.—Poorly sealed and insulated doors will lower the over-all efficiency of a storage to an extent greatly out of proportion to their size, due to the interchange of outside air by convection and by infiltration. This air leakage may be reduced by tight-fitting doors or by air-stops, Figure 14. However, it is almost impossible to prevent doors in a storage from expanding and thereby making it difficult, if not impossible, to open or close them. It is much better to rely on some gasket material for the airtight seal and construct the door with ample all-round clearance, as shown in Figure 13.

Double doors will serve the same purpose as a single heavy door and are much easier to construct although not as convenient to use. The commercial cold storage doors are furnished with their frames all ready to install but are expensive. In view of their excellent construction and long life they are often the most economical over an extended period.

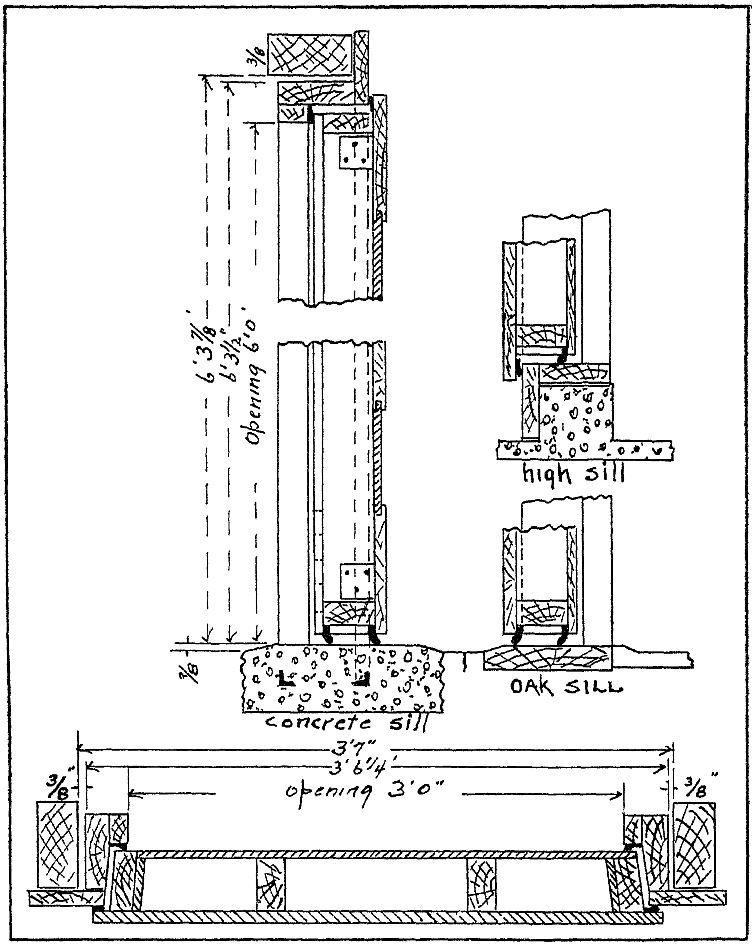

Fig. 13.—Design and dimensions of a cold storage door

Hardware for such doors and detailed plans for their construction are available from several manufacturers Note the three types of sills used and the impossibility of such doors sticking through expansion or warping

The cold storage door manufacturers and others now sell special hardware (clasp and hinges) with directions for constructing inexpensive but well insulated doors of all shapes and sizes, Figures 13 and 14. The minimum size in the clear should be 3 by 6 feet, though a size of 4 by 6½ to 7 is usually more satisfactory. Ventilator doors around the ceiling level are opened from the floor by means of ropes or a narrow walk constructed at their level. Balsam wool, Palco Bark, or Re-granulated Cork are very light fluffy materials excellent for door insulation of the type shown in Figure 13. For the same reason the reflective types of insulation, such as Silvercote and Metallation, should serve well as insulation where light weight doors are desired. The solid types, as shown in Figure 14, are more easily constructed although they are heavier for an equal amount of insulation.

Ventilating flues.—Ventilating flues are designed to carry large volumes of air rapidly and therefore require special care in their construction. If they are to function efficiently they must be insulated, for their action depends on retaining warmth of the air passing through them. This warm air is light in weight and is pushed up the flue by the heavier outdoor air which enters through the inlets. In case the air is cooled as it starts up the flue it will be slowed up or stopped before it reaches the outlet. It may become even cooler than the storage air and the direction of flow will be reversed down into the storage. Many have undoubtedly seen this reversing of the air currents and been unaware of its cause. An uninsulated metal flue passing up through a cold barn or other loft will be most liable to function poorly for the reason just mentioned.

To facilitate the movement of large volumes of air with the minimum sized flues, smooth boards should run lengthwise of the flues and all bracing, cross members, and other obstructions should be on the outside. Any angles or curves will tend to slow down the air and should be avoided or made large with no abrupt turns. It is possible further to increase the air moved through a flue of given size by 30 to 40 per cent through the construction of a curved entrance since air, like water, will contract into a smaller volume when passing through a straight-edged opening. This is explained by the interference of the air currents entering obliquely around the margins, causing a contraction of the air stream which may reduce the actual flow to about 65 per cent of the theoretical (see discussion under fans).

One ½-inch layer of insulation between two layers of boards, lined with paper, should be sufficient protection for flues. The ventilator top, if home-made, should have a clear opening on all four sides unrestricted by louver boards or close-mesh screens, Figure 14. Doors which may be closed in the winter time may be provided at the ventilator head opening and at the bottom.

MISCELLANEOUS EQUIPMENT

Roof ventilators.—Of the equipment which may be used in conjunction with a common storage, roof ventilators and power exhaust fans warrant some discussion.

Numerous automatic roof ventilators of many different styles have been developed with the idea of increasing the outflow of air from an open flue through the action of the wind. The grower is usually unable to make an intelligent choice since he can not test the equipment for himself. Since the cost of patented ventilators is frequently high, a grower should require a guarantee of performance to protect himself fully.

Investigators (10, 13) point out the surprising fact that the best exhaust is obtained with a very simple construction. The best ventilators will seldom exhaust more than one and one-half times as much air as from an open pipe of the same diameter and then only during high winds. When no wind is blowing these same ventilators exhaust down to 90 or even 80 per cent of that exhausted by an open pipe.

Calderwood and Mack (10) divide ventilators into five classes: plain (mushroom) stationary, stationary siphoning, plain rotary, rotary siphoning, and turbine. The United States Bureau of Standards (13) at the conclusion of their tests reported: "No general statement can be made as to the relative merits of rotary and stationary, or mushroom and siphon ventilators. The performance depends on the particular models. It is possible to build a good stationary ventilator as well as a good rotary ventilator, and there are poor ventilators of each type".

The same authority stated: "The most effective way of obtaining a large volume of air exhaust is by making use of the region of low pressure produced at the back of a properly designed obstacle. A familiar example is the outward rush of air through windows in a room (low pressure area) when a strong wind is striking (the obstacle) the opposite side of the building (high pressure area). It is best not to allow the air to enter the ventilator for it must then be exhausted and will be exhausted at the expense of the air in the ventilator pipe".

It is possible for a grower to construct his own ventilator or have it made for him by a local tinner. Because the simple type seems to function as well as the more complicated, a considerable saving may be made by an intelligent use of the information obtained by these investigators. Roof ventilators equipped with power exhaust fans may also be obtained (See section on ventilation for air moved through flues).[12]

Power exhaust fans.—The use of power fans in storages to draw cool air through the fruit has been considered as unnecessary by some authorities. Although it is possible to cool fruit with air moved by gravity and wind, in practice it is difficult, for there are so many days when the temperature differential between the inside and the outside air is slight or entirely lacking. Also, there may be little or no wind during these periods. In addition to these adverse conditions the fruit is at a high temperature during this early storage period and its preservation requires that every possible advantage be taken of any reduction in outside temperatures. For these and other obvious reasons, it is often decidedly valuable to have positive control over the volume of air moving through the storage. The only objection offered to forced ventilation by power fans is its cost. The facts show this cost to be very low when using the newer, more efficient propeller-blade fans. Such fans are an expense for current only a relatively short portion of the storage season (75 to 100 nights) and may be used to supplement a gravity system. Upon the advent of low outside air temperatures, small amounts of ventilation are sufficient and are easily obtained without the use of fans.

A grower may be fortunate in obtaining a used fan at a very low cost. When a new fan is purchased, it should be selected on the basis of its free discharge capacity at a given power input. Fans using the airplane propeller type of blade will be found the most efficient for exhausting air against no pressure. By means of Table 4, growers may readily compare fan ratings, determine horsepower, kilowatts, and size of fans needed to secure a given number of air changes in their storages.

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[12]Conservative figures of air discharged for the best types of ventilators now on the market, under conditions of unrestricted flow of air to the ventilator, are given by the following equation (2): $Q = A \left[\frac{36\sqrt{H}\,(t_1\text{-}t_2)}{6+V} + 20V\right]$

Q equals cubic feet of air exhausted per hour through a ventilator having a free area at the throat of A square inches, mounted on a roof at a height of H feet from the center of the ventilator outlet to the inlet opening of the building, and with a wind velocity of V miles per hour and average temperature of t_1 inside and t_2 outside. High class ventilators (for instance, those of the ejector type) will under favorable conditions discharge 25 per cent more air than the above formula would indicate. Capacities are lower, on the other hand, if ventilators of lower efficiency are used, if the flow of air into or through the building is restricted, or if the ventilator is not exposed to the free sweep of the wind. Tests occasionally show considerably higher discharge rates over short periods of time.

TABLE 4.—Free Discharge Capacity of Propeller Fans at Various Power Input Values*

Horsepower input to fan blades for various values of efficiency							Free discharge capacity, cubic feet per minute										
Efficiency, per cent							Diameter of fan opening, inches										
30	40	50	60	70	80	100	12	15	18	21	24	27	30	33	36	42	48
0.067	0.050	0.040	0.033	0.029	0.025	0.02	1,079	1,453	1,854	2,276	2,720	3,183	3,663	4,159	4,671	5,736	6,854
0.167	0.125	0.100	0.083	0.071	0.063	0.05	1,465	1,973	2,515	3,090	3,692	4,319	4,971	5,644	6,339	7,785	9,302
0.333	0.250	0.200	0.167	0.143	0.125	0.10	1,846	2,485	3,169	3,893	4,651	5,442	6,263	7,112	7,986	9,809	11,720
0.833	0.625	0.500	0.417	0.358	0.313	0.25	2,505	3,373	4,301	5,283	6,313	7,386	8,500	9,652	10,839	13,313	15,907
1.67	1.25	1.00	0.833	0.715	0.625	0.50	3,156	4,250	5,419	6,656	7,953	9,306	10,710	12,161	13,656	16,773	20,041
2.50	1.87	1.50	1.25	1.07	0.937	0.75	3,613	4,865	6,204	7,620	9,104	10,652	12,260	13,920	15,632	19,200	22,941
3.33	2.50	2.00	1.67	1.43	1.25	1.00	3,977	5,355	6,828	8,386	10,021	11,724	13,493	15,321	17,205	21,132	25,250
5.00	3.75	3.00	2.50	2.14	1.88	1.50	4,552	6,130	7,816	9,600	11,471	13,421	15,446	17,539	19,695	24,190	28,904
6.67	5.00	4.00	3.33	2.86	2.50	2.00	5,010	6,747	8,603	10,566	12,625	14,772	17,001	19,304	21,677	26,625	31,814

*Portion of a table by A. I. Brown in Ohio State Univ. Studies, Eng. Series, Vol. 2, No. 3, Part I, 1933. (Eng. Exp. Sta. Bull. 77).

Unfortunately, manufacturers are not yet required to base their fan ratings on the standard test code method of the American Society of Heating and Ventilating Engineers and consequently no common basis for comparison is available. The horsepower and frequently the wattage input are stamped on fan motors and this information, together with the diameter of the blades, will enable a grower to determine the correct rating of any fan at any efficiency by the use of Table 4. One may rarely expect an efficiency as high as 60 per cent, and the more common ratings are based on efficiencies of from 30 to 50 per cent (9).

The application of the principles of hydraulics which have been known for some time to the design of the ring surrounding the blades of a fan has increased its efficiency by several per cent (22 per cent). This increase in capacity was obtained by the addition of a rounded or bell-shaped entrance piece attached to the inlet side of the cylindrical fan ring, which reduced the leakage or recirculation at the blade tips and produced in effect the equivalent of an increase in the area of the ring opening (9). This principle may also be applied to flues, as previously suggested.

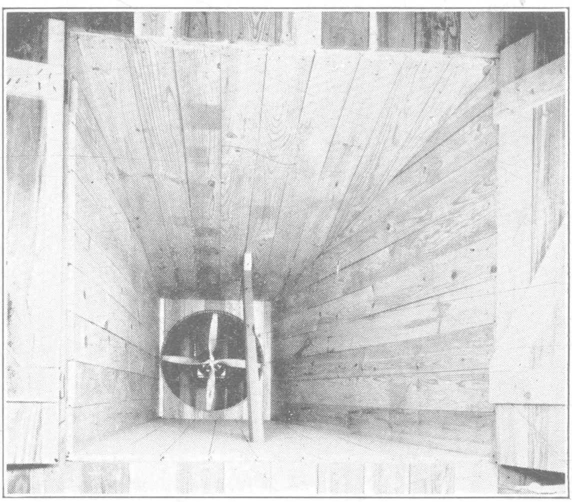

Fig. 14.—Electric-powered exhaust fan for forced ventilation in an apple storage

A four-blade, 27-inch, propeller-type fan with an improved (patented) curved ring encircling the blades, installed on one side of an outlet flue to exhaust horizontally into an open room. Note the smooth, flaring sides to the air shaft which offer the minimum resistance to air movement. This fan is supplementary to a gravity ventilation system and on single phase, 110-volt current consumes 660 watts (½ horsepower) and produces 10 air changes per hour (8000 cubic feet per minute) (50 to 60 per cent efficient) in the storage room shown in Figure 10.

Since the power required to move any given volume of air through openings of different diameters varies as the square of the velocity or inversely as the fourth power of the ratio of diameters, the cost of ventilation by power fans can readily be reduced to a small figure by increasing the fan size (Table 4). This increases the original investment and may be a more important item than the cost of current but is always more economical than purchasing two smaller fans to move the same volume of air.

Calculations based on the figures in Table 4 show that the cost for current for a fan changing the storage air at least 10 times per hour need not be more than one cent per hour of operation and in the majority of cases will cost somewhat less. Thus, a conservative figure for the storage season would be $25, which could hardly be considered costly for cooling 10,000 bushels of apples.

Where electric power is not available, a gasoline engine will serve very well if belted to a fan taken from an old truck or tractor. Fruit growers frequently have one to several gasoline motors for use with dusters, sprayers, water pumps, and graders which are usually portable and not in use all of the time. Provided such an engine is available at least for use during the night, the investment will be considerably less than for an outlet flue. Care must be taken in mounting the fan to secure the maximum efficiency, and the volume of air exhausted from the storage should be checked by some ventilating engineer.

THE VENTILATION OF THE STORAGE

Many of the older storages in Ohio, although well insulated, are inadequately equipped for ventilation. This is undoubtedly due to misconceptions concerning the volume of air carried by small flues and inlet openings and the cooling capacity of that air.

There appears to be little agreement among the few workers who have reported on the volume of air necessary to cool fruit in common storages.

Marshall (19) in Michigan, as a result of air-flow tests in several storages, concludes that an average of 50 cubic feet of air under ordinary fall conditions is required to cool a bushel of apples one degree, when there is a temperature difference of 4 to 5 degrees F. Carrick and Goodman (11) in New York calculated the theoretical volume of air (450 cubic feet) necessary to pass through the storage for each bushel of apples stored to reduce the temperature one degree when the outside temperature is only 10 degrees lower than that of the fruit. Magness (15) calculated that the volume would need to be 150 cubic feet for the same degree of cooling under like conditions; and Andrews (5) claims the figure should be over 207 cubic feet. Strange to say, the calculated figures prove to be much higher than the figure found by experimental methods.

It is difficult to determine the heat to be removed in cooling apples to any storage temperature. The specific heat of the fruit, the rate at which it produces heat (by respiration), and its initial and final temperatures are the main factors involved. If the fruit were cooled instantaneously, the heat to be removed would be only the number of British thermal units obtained by multiplying the specific heat (0.90-0.92) of an apple by the difference between the initial and the final temperatures and this product by the weight of the fruit in pounds. This is usually called the "sensible" heat and is the only source of heat included in the Carrick and Goodman (11) calculations. The cooling process, however, requires time, and during the interval additional heat is produced by the respiration of the stored fruit. This heat evolution varies considerably with the product and its environment; Table 5 shows the approximate amounts of sensible heat and of heat produced by respiration.

The per cent of the total cooling load due to the heat of respiration is greater at the higher temperatures, and over any range of temperatures may amount to several times the sensible heat removed if the cooling takes place very slowly.

TABLE 5.—Heat Removed in Cooling One Ton of Apples 10 Degrees in 10 Days
Initial temperatures from 85 to 35° F.

Temperature range °F.	Heat of respiration*	Sensible heat	Total cooling load	Per cent of total cooling load due to respiration
	B. t. u.	*B. t. u.*	*B. t. u.*	*Pct.*
85 to 75	62,000	18,000	80,000	78
75 to 65	53,000	18,000	71,000	75
65 to 55	44,000	18,000	62,000	71
55 to 45	27,000	18,000	45,000	60
45 to 35	16,000	18,000	34,000	47
35 to 32	7,000	18,000	25,000	28
85 to 32	209,000	108,000	317,000	66

*Heat of respiration varies with several factors and the values above are computed averages (20).

The design of a storage ventilation system must be adequate to care for the maximum cooling load which will be encountered. Making the necessary calculations should fix approximately the volume of air necessary for a given rate of cooling. One British thermal unit will raise the temperature of one pound (or 13.2 cubic feet) of air with the moisture content usually found in apple storages approximately 4.13 degrees F. The same amount of heat (1 B. t. u.) then will raise the temperature of one cubic foot of air 54.5 degrees ($4.13 \times 13.2 = 54.5$), or 54.5 cubic feet of air 1 degree F.

Assuming an average cooling of 1 degree F. per day, which is not uncommon in Ohio, the total cooling load for 10 days during the early fall might be 80,000 B. t. u. per ton of fruit, Table 5. For one day the cooling would be 8000 B. t. u. per ton ($\frac{80,000}{10}$) or 4 B. t. u. per pound ($\frac{8000}{2000}$), and 180 B. t. u. ($4 \times 45 = 180$) per bushel (average weight 45 pounds), or enough heat to raise the temperature of 9810 cubic feet of air 1 degree ($54.5 \times 180 = 9810$). If the outdoor air is 10 degrees cooler than that of the storage room, it will be necessary to pass 981 cubic feet of air ($\frac{9810}{10} = 981$) through the storage for each bushel of apples stored to reduce the temperature of the fruit 1 degree F., provided apples and air reach the same temperature, a condition that will not be obtained in practice. Neither does this provide for reducing the temperature of the floor, walls, ceiling, and fruit containers.

It is readily evident that an exact value can not be obtained, and it is customary to double the value as calculated above to include the heat removed from sources other than the fruit itself.

In order that the volume of air needed to cool one bushel of fruit shall be a whole number, the 981 cubic feet will be multiplied by 2.2 rather than 2 as suggested; the volume of air then becomes 2160 cubic feet per bushel of fruit. Since usually the cooling can be done only during the night and early morning hours, the time limit will not be more than 12 hours per day, so that air must be passed at the rate of 180 cubic feet per hour or 3 cubic feet per bushel per minute ($\frac{2160}{12 \times 60} = 3$).

It should be understood that 3 cubic feet is an approximate figure only, since it is impossible to determine the actual rate of cooling which could be obtained in all cases.

It is seldom that a grower will make provision for moving 3 cubic feet of air per bushel per minute through his storage since this is the requirement only during the early weeks of storage and the cost of providing it is considerable. It seems more economical to cool the fruit somewhat slower than 1 degree per day during this early period, and, to accomplish this, 1 cubic foot per bushel per minute may be considered adequate. To choose a fan of the proper capacity for use in storages of any size, the product of the dimensions of the storage room in feet will give the capacity in cubic feet which, when divided by 2.5, gives the capacity in bushels of fruit. This is equal to the cubic feet of air per minute which should be moved through the storage. If an exhaust fan is to be used, Table 4 shows the size which will be required at various levels of power and efficiency.

The cost of purchase and operation is not out of proportion to the benefits derived and may be considered less than the cost of providing the same ventilation by means of flues.

The size of flue required to move the same quantity of air moved by the fan may be readily determined from Table 6, in which are given the cubic feet of air moved per hour per square foot of flue opening for various wind velocities. The requirements for cooling a bushel of apples amount to 60 (1 x 60) cubic feet per hour. It is customary to rate fans in cubic feet per minute and ventilators in cubic feet per hour.

TABLE 6.—Capacity of Ventflues

Cubic feet per hour per square foot for various heights, wind velocities, and temperature differentials*

Height in feet	Temperature differentials						
	1°	3°	5°	7°	10°	15°	20°
	Wind velocity 1 mile per hour						
20	6,192	8,616	10,286	11,643	13,353	15,707	17,691
30	6,936	9,906	11,950	13,612	15,707	18,590	21,020
40	7,564	10,993	13,353	15,272	17,691	21,020	23,826
50	8,117	11,950	14,589	16,735	19,440	23,161	26,299
	4 miles per hour						
20	20,794	27,582	32,256	36,055	40,845	47,435	52,992
30	22,878	31,192	36,916	41,569	47,435	55,507	62,312
40	24,634	34,235	40,845	46,218	52,992	62,312	70,170
50	26,182	36,916	44,306	50,313	57,885	68,308	77,092
	6 miles per hour						
20	28,866	37,358	43,200	47,949	53,936	62,173	69,120
30	31,476	41,869	49,025	54,842	62,173	72,264	80,770
40	33,673	45,674	53,936	60,652	69,120	80,770	90,592
50	35,608	49,025	58,263	65,771	75,239	88,265	99,246
	10 miles per hour						
20	43,286	53,897	61,200	67,136	74,619	84,917	93,600
30	46,545	59,537	68,481	75,751	84,917	97,530	108,163
40	49,291	64,292	74,619	83,015	93,600	108,163	120,440
50	51,709	68,481	80,028	89,414	101,248	117,530	131,257

*Computed by formula, footnote on Page 38.

The values given in Table 6 were computed by means of a formula (footnote Page 38) and are conservative for the best types of ventilators now on the market under conditions of unrestricted flow of air to the ventilator. Discharges may vary by 25 per cent or more, depending on the ventilator, restrictions offered to the flow of air into or through the storage, and the location of the ventilator as to exposure to the free sweep of the wind. In the smaller sizes of ventilators (12 inches or less in throat diameter) the air discharge per square inch of cross-sectional area is reduced on account of the frictional resistance and in some ventilators on account of reduction of free area by supports, braces, etc.

The wind velocities which are effective in producing draft in storages probably do not have a yearly average in most parts of Ohio greater than 4 to 6 miles per hour. The temperature difference effective in ventilation is perhaps not higher on the average than 3 to 10 degrees F. during the early storage period. If a flue with a simple open top (Fig. 15) is considered, the

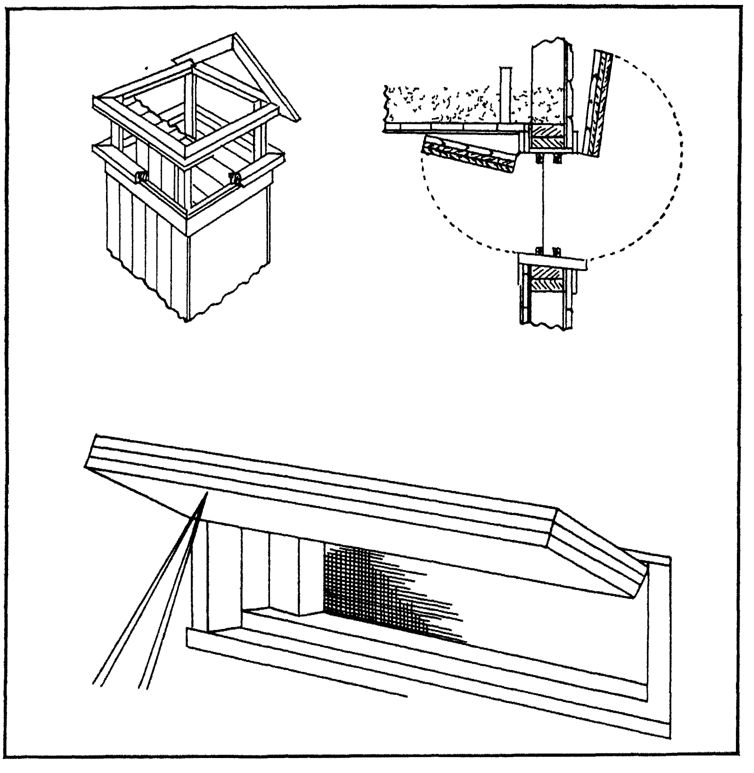

Fig. 15.—Home-made vent openings showing construction details*

The ventilator head (top left) should have a clear opening on all four sides unrestricted by louver boards or fine screening The height of the clear opening should be one-third the length of one side. Intermediate posts extended to the roof plate should be used on large ventheads The bottom of the opening should be 2 feet above the highest part of the roof

Single or double doors constructed of layers of ⅞-inch matched lumber and board insulation are effective for side wall inlets only if deep door stops are used. Hardware cloth screen should be fastened between the stops

*Adapted from Carrick and Goodman (11).

capacities given in Table 6 under 1 mile per hour wind velocity should be employed in all calculations; a 4-mile average wind velocity might be assumed for all flues with commercial ventilator heads. Flues less than 20 feet from the floor to the venthead or more than 4 feet above the highest part of the roof are impracticable.

The system should have ample capacity. Moreover, it will prove much less expensive to install an adequate system when building than to change it later. Quick cooling is always preferable to slow cooling, and a system which needs to be closed much of the time in cool weather is more satisfactory than one that is not large enough to hasten cooling the early part of the storage season.

Dividing the bushel capacity of a storage by any figure in Table 6 and multiplying the quotient by 60 will give the area in square feet of the flue opening required to cool the fruit from 0 to 1 degree F. per day. Notice that at the lower temperature differences less air will move through flues and the same air will remove less heat from the fruit than at the higher temperature differences.

Flues from 7 to 12 square feet in cross section are commonly used in storages. Flues with the venthead 20 feet from the floor of the storage and operating with a 5 degree F. temperature difference and 1-mile average wind velocity will exhaust approximately 10,000 cubic feet per square foot per hour, Table 6. Storages holding 5, 7.5, 12.5, 15, and 20 thousand bushels would then require flues with cross-sectional areas of 30, 45, 60, 75, and 120 square feet ($\frac{5000}{10{,}000} \times 60 = 30$), respectively. The storages of 15- to 20-thousand bushel capacity would require a large number (6 to 10) of flues of from 36 x 40 to 48 x 50 inches or a smaller number of large cross section. Doubling the height of the flue to 40 feet would reduce these requirements by one-third. Table 7 gives some suggestion as to number and size of outlets for storages of various sizes.

The inlet openings are much less expensive to construct than the outlet flues, and consequently there is less excuse for making them inadequate in size or number. They should never be smaller than 2 square feet in cross-sectional area and preferably larger and should be well spaced to distribute the incoming air through the fruit. In order that the outlet flues shall function properly, air must have ready access to them. For this reason it is customary to provide a total inlet area twice the outlet area. Spacing the inlet openings on 10 to 20 foot centers will usually provide the correct number and spacing for all types of storages. For example, using openings approximately 3 x 4 feet, it would require 5, 7, 10, 12, 15, and 18 openings for storages of 5, 7.5, 10, 12.5, 15, and 20-thousand bushel capacity, respectively. By making the openings somewhat smaller more could be used to advantage. Usually two openings on each end of the storage (40 feet wide) are sufficient and the remainder may be equally spaced on the remaining two sides. Table 7 gives some suggestions as to number and size of inlet openings for storages of various sizes.

REMODELING FARM STRUCTURES

Barn basements and other portions of farm buildings may be remodeled at a moderate cost and serve very well the needs of the grower with a small acreage of fruit. The problems are diverse, for each structure presents a situation somewhat unlike any other.

TABLE 7.—Outlet and Inlet Flue and Fan Sizes
For storages of varying capacities

Capacity of storage room		Dimensions of storage room	Number of intakes*	Size of intakes	Outlet ventflues								Fan sizes	
					20 feet†				40 feet				Approximate diameter of fan‡	Approximate current consumption per hour§
					Homemade venthead		Patented venthead		Homemade venthead		Patented venthead			
					No.	Size	No.	Size	No.	Size	No.	Size		
Bu.	*Cu.ft.*	*Ft.*		*Ft.*		*Ft.*		*In.*		*Ft.*		*In.*	*In.*	*Kilowatt-hours*
5,000	12,500	26 x 40 x 12	5 10	3 x 4 2 x 3	1	4 x 5	1	36	1	4 x 4	1	30	24 to 27	0.186 to 0.149
7,500	18,700	30 x 52 x 12	7 12	3 x 4 2 x 4	2	4 x 4	1	42	1	5 x 5	1	40	27 to 30	0.466 to 0.447
10,000	25,200	34 x 62 x 12	10 15	3 x 4 2 x 4	2	5 x 5	1 2	48 36	2	4 x 5	1 2	42 30	30 to 33	0.932 to 0.466
12,500	31,100	36 x 72 x 12	12 16	3 x 4 3 x 3	3	4 x 5	1 2 3	54 40 30	2	4 x 5	1 2	48 36	33 to 36	1.118 to 0.932
15,000	37,400	38 x 82 x 12	15 18	3 x 4 3 x 3	4	4 x 4½	1 2 3 4	60 48 36 30	3	4 x 4½	1 2 3	54 40 30	36 to 42	1.394 to 1.000
20,000	48,000	40 x 100 x 12	20	3 x 4	5	4 x 4½	1 2 3 4	72 48 42 36	4	4 x 4½	1 2 3	66 42 36	42 to 48	1.394 to 0.932

*The larger number of intakes is preferred.
†The top of the flue should be at least 2 feet above the highest part of the roof.
‡Fan size is based on the capacities given in Table 4 and an efficiency of 40 to 50 per cent.
§Current consumption based on horsepower to fan as given in Table 4 and the factor, $\text{Kilowatt-hours} = \frac{\text{Horsepower}}{1.341}$.

The typical frame barn with sheeting nailed on the outside of heavy hewn timbers is easily insulated with one of the rigid-board or flexible types of insulation. The insulation is cut to fit between frame members, and successive layers are separated by furring strips. In this manner sheeting need not be removed, but it is well to line the latter with waterproof paper and to waterproof the inside surface of the last layer of insulation with a good oil paint. Two by fours nailed crosswise of the old rafters will furnish the necessary nailing base for insulating board 4 feet in width. Where the loose-fill type of material is available in quantity, some prefer merely to line the space between the barn timbers with paper and fill with sawdust, shavings, or processed material and board over the inside with matched lumber. Many growers do not insulate sufficiently nor do they seal the wall tightly and poor results ensue. Still another but more costly method is to construct a double wall by erecting studs on the outside or inside of the old wall and applying insulation to the new portion only. Occasionally the frame wall rests on a flared masonry foundation 2 or more feet above the storage floor. To insulate this portion of the wall it is necessary to construct a frame and fill the space between foundation and sheeting with a loose-fill material; the latter should be carried well up into the wall above. Where earth or cinders bank the foundation on the outside, no insulation will be necessary. It is well to lay the wall plate in concrete on the old foundation wall to insure an airtight seal at this junction.

Where a bank barn has a stone wall 18 to 24 inches thick it may not be advisable to add additional insulation, particularly when a portion of the wall is banked with earth. An 8-inch concrete or concrete-block wall may be furred and insulation applied as described above. An alternative method consists of erecting inside a 4-inch glazed tile wall leaving a 2 to 4-inch space to be filled with a good dry-fill insulation.

Rodents are likely to cause more or less trouble in all storages and especially in barn basements; consequently, to guard against their entrance a ¼-inch mesh wire screen (hardware cloth) may be used to cover the floor and extend well up the walls. Metal lath and plaster and concrete floors are also rodent proof and are preferred by many.

FALL AND WINTER MANAGEMENT

It is deemed unwise to indicate how the fruit should be placed in a storage, for the method used depends to a large extent on the method of ventilation and on the position and distribution of the intakes and outlets. More often, space in a storage in the fall is at a considerable premium, and at the sacrifice of a slightly higher fruit temperature in parts of the room the crates are stacked close to the walls and ceiling. This also explains why false floors are not considered justifiable when the condition of the fruit and costs are balanced one against the other during the season. The grower too frequently allows more or less space between the stacked fruit and walls and ceiling with no thought for the ventilation of the fruit in the center of the room. A proper balance would be so to arrange the tiers of fruit as to direct the incoming air past as much exterior crate surface as possible. In this way short circuiting of the air from the intake to outlet without obtaining the maximum cooling action is avoided with the minimum of lost space.

This may be accomplished by directing the rows of crates towards the outlet with 2- to 3-inch spaces between tiers and very little more space at the walls. Frequently, canvas hung at the correct position or crates stacked to form an obstruction will force the air to travel only through the fruit (partially filled storage) as it moves to the outlets. In addition, especially with the forced system of ventilation, it is wise to open only the intakes farthest from the fan and thus force all the air to travel through the maximum quantity of fruit before it can leave the storage.

A good distribution of intakes aids in the proper air movement and allows the grower to take advantage of winds which add considerably to the forces moving the air. It is essential, where intakes at the ceiling level are used, to stack the crates only to the bottom of the openings in order to allow rapid air movement across the storage, a requisite for this type of construction. The more rapid the flow of cooler outside air through the building, the more quickly will the fruit temperature be reduced.

Thermometers placed inside and outside the storage room are essential, for the judicious manager will be prompt in opening the ventilators at the earliest indication of cooler outside air and as prompt to close them when the two temperatures are the same. It is just as important to close the house tightly when it is warmer out-of-doors as it is to open the ventilating system and operate the fan when it is cooler outside than inside.

When ideal storage temperatures have been attained, it is sufficient to open the storage for short periods only on bright, mild days. Some growers prefer to keep one outlet slightly open most of the time to allow the escape of generated heat and gases during this period.

Both the condition of the fruit and the relative humidity of the air should be closely watched. Small hygrometers may be purchased for a few dollars with which the relative humidity can be easily and quickly determined. Eighty-five to 88 per cent seems desirable, and when the relative humidity falls below the minimum figure water should be added to the floor over as large a surface as possible. If water under pressure is available it will do no harm to wet crates and walls with the hose since rapid evaporation soon dries these surfaces.

No one factor is more responsible for unsatisfactory performance of common or air-cooled storages than the lack of attention to detail on the part of the manager. An air-cooled storage will not operate automatically, and therefore only through the constant vigilance of the operator can the fruit be maintained in the best condition in these storages.

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